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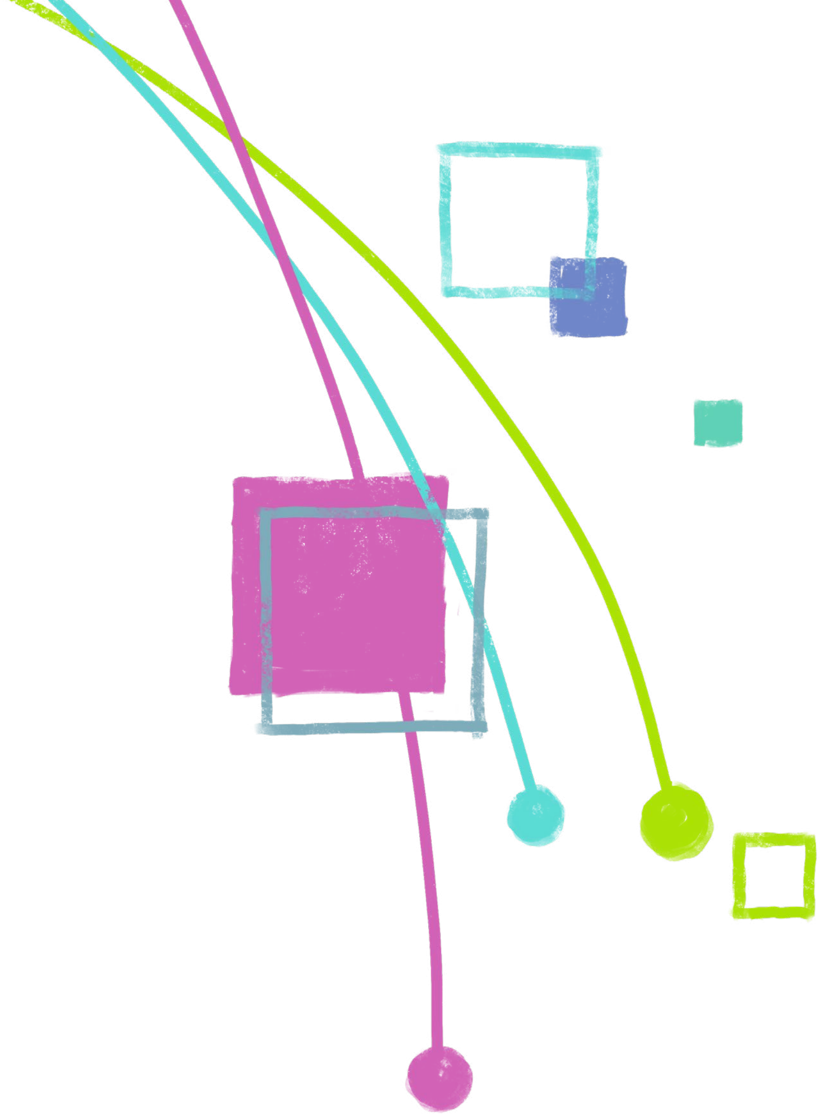
Steering Research and Innovation for Global Goals

CHANGING DIRECTIONS

Steering science, technology and innovation towards the Sustainable Development Goals



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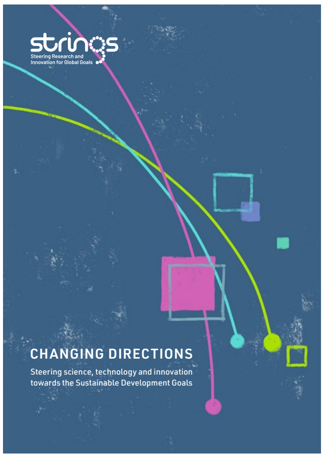
For more information about the project visit: www.strings.org.uk



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Steering Research and Innovation for Global Goals

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2. http://strings.org.uk/strings-webinar-recording-how-do-evidence-based-models-contribute-to-the-sdgs/
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6. http://strings.org.uk/overview-of-the-strings-project-workshop-2022/

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Steering Research and Innovation for Global Goals

The reflections and conclusions that emerge from the report add to the arguments that fundamental changes are needed in science systems and institutions, including those of government policy and funding, if real progress is to be made.

Its conclusions merit deep reflection by the science and policy communities.

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THINKING DIFFERENTLY ABOUT THE ROLE OF SCIENCE AND OUR SUSTAINABLE FUTURES

There is increasing recognition that, despite all the potential of science to contribute to equitable and sustainable social, economic and environmental futures, there is a gap between the claims of science and its delivery. The Sustainable Development Goals (SDGs) were adopted unanimously in 2015 by United Nations Member States. They were a mix of specific, interconnected and somewhat vague objectives. Importantly, unlike the earlier Millennium Development Goals, they placed obligations on high-income countries (HICs) as well as low- and middle-income countries. However, every assessment of progress on the SDGs has shown dismal results, even on those related to climate change, where much has been claimed by science and policy communities.

Even before the SDGs were formally adopted, the science policy community identified that the goals were intertwined and that considering them in a siloed manner would not be ideal.[1] Nevertheless, most science funding continues to be narrowly focused in disciplinary silos. Further, the current funding models and incentives within the institutions of the science community, especially in HICs where most funding for science originates, do not necessarily support the research approaches and related outcomes that society clearly needs. Academics might claim their research is directly relevant to the SDGs, but little has changed since 2015. The pervasive culture of bibliometrics, rankings, and project funding has not diminished. In addition, the dominating policy focus within HIC policy communities on the direct economic impacts of research works against the very research that is most needed.

What is desperately needed is a new range of tools that promote meaningful and tractable focus on actionable knowledge. This means defining the problems at the community level and developing transdisciplinary and systems approaches to research. It means accepting that end users of research, including the community, must be engaged from the outset in the co-design and co-creation of scientifically rigorous and socially robust knowledge. It means that key outputs may not appear in the journals of record on which the academic industry has become based. Natural sciences must engage more meaningfully with social and human sciences and, indeed, with other knowledge systems.

Transdisciplinary research is hard; it is very different in approach from traditional research paradigms. Funders, institutions, academies and others will have to adjust their understanding of research if progress is to be significant. HIC research funders must recognize that it is in their interests to support and promote research led by and shaped by experts in low- and middle-income countries, and avoid the somewhat patronizing attitude that has too often dominated in internationally focused research.

This final report of the STRINGS project is a most valuable addition to other arguments, such as *Unleashing Science*[2] and the *Global Sustainable Development Reports*,[3] that have highlighted the mismatch between where science activity largely sits and society's needs. Its contribution is distinctive. It reports on a particularly innovative bibliometric analysis supported by a survey and illustrative case analyses. The reflections and conclusions that emerge add to the arguments that fundamental changes are needed in science systems and institutions, including those of government policy and funding, if real progress is to be made. The report makes many telling and empirically supported points which support this general argument.

Its conclusions merit deep reflection by the science and policy communities.

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1. International Council for Science 2017: https://council.science/wp-content/uploads/2017/05/SDGs-Guide-to-Interactions.pdf
2. International Science Council 2021: https://council.science/wp-content/uploads/2020/06/202108_Unleashing-Science_Final.pdf
3. United Nations Department of Economic and Social Affairs 2019: https://sdgs.un.org/publications/future-now-science-achieving-sustainable-development-gsdr-2019-24576

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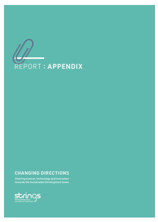
APPENDIX

The Appendix and Supplementary Figures are supplied as seperate documents, which can be downloaded from **www.strings.ac.uk**



REPORT : **SNAPSHOT**

REPORT : **SNAPSHOT**

GLARING PROBLEMS AND RECOMMENDATIONS

This report presents the results of the Steering Research and Innovation for Global Goals (STRINGS) project – a major global study into the alignment between science, technology and innovation (STI) and the Sustainable Development Goals (SDGs). It highlights a glaring mismatch between STI and the SDGs; warns that, if this mismatch is not addressed, it will undermine progress on the SDGs; and makes recommendations about how to tackle this imbalance.

What must change: The main problems

Our findings show:

A problem of orientations

Most published research (60%-80%) and patented inventive activities (95%-98%) are poorly aligned with the SDGs.

A problem of inequalities

High-income countries (HICs) and upper-middle income countries (UMICs) contribute disproportionally to such misalignment: only 30-40% of research in HICs and UMICs is related to SDGs. In low-income countries (LICs), 60-80% of the research is related to the SDGs, but these countries account for only 0.2% of globally produced research. Since most global research is produced in HICs without collaboration with researchers in LICs (where SDG challenges are most severe), there is little chance that STI can address contextual challenges.

A problem of focus

Even though a majority of stakeholders consider social, policy and grassroots innovations critical to addressing the SDGs, support for these types and forms of innovations, and related research on complex underlying social issues of deprivation, inequality and conflict, lags far behind research and investment in hard technologies.

A problem of knowledge siloes

There is currently too little effort to combine research and innovation on technical interventions with research that more directly addresses complex underlying social issues. This is despite evidence that different types of STI have divergent impacts on SDG targets, leading to synergies and tensions.

A problem of regional misalignment

Countries' research priorities are often not aligned with their main SDG challenges. This is the case for LICs such as India (which does not prioritize research on hunger or gender equality), as well as for most HICs, including the USA, which do not prioritize research on the major environmental challenges associated with unsustainable consumption and production patterns. Globally, military-related research is typically highly funded, but military aims feature nowhere in the SDGs.

A problem of closing off relevant STI pathways

Diverse contexts, priorities, values and interests mean there are many possible STI pathways to address specific SDG-related challenges. However, it remains the case that a single pathway is usually dominant. For example, when addressing SDG 2 (Zero hunger), breeding new seeds in laboratories might be prioritized above conserving and exchanging seeds from indigenous plant varieties. Similarly, closed forms of science might be prioritized over open science practices when addressing neglected diseases in SDG 3 (Good health and well-being).

A problem of data

There is little systematic understanding about what exactly is being supported by STI investments, where, and for what purposes, and a similar dearth of data about what knowledge is being produced and used beyond formal R&D processes. The STRINGS project has pulled together comprehensive data sets, surveys and in-depth case studies to enable decision makers to better understand and shape their options. But a major investment is also needed to gather data about knowledge and innovation investment and production across all contexts and sectors.

The result of the above problems is that the world's efforts in STI are insufficiently contributing to the overarching objectives, encapsulated in the SDGs, that the world has decided matter most.

How to bring about change: Our main recommendations

This report provides evidence and tools to help enable more active debate and exploration of alternative and more inclusive STI strategies, whether within nations, regions or at a global level. It provides several recommendations for research funders, aid organizations, the academic community, development agencies, policymakers, governments and civil society organizations, as summarized below.

Increase funding for SDG-related research and innovation – particularly in LICs; on underlying social issues; social, policy and grassroots innovations; and on issues that are relevant to a region or context – to improve alignment between SDG priorities and STI portfolios.

This includes:

- involving a more diverse set of actors and interests in research funding decisions
- creating opportunities for more equitable knowledge transfers and capacity-building
- enabling more open and participatory decision-making that identifies and implements plural funding priorities
- adopting a more holistic approach to research funding design and evaluation, valuing constructive and equitable partnerships, and interdisciplinary and transdisciplinary research

Promote a rich diversity of STI pathways to address specific SDG challenges.

This includes:

- ensuring that decisions about which STI pathways to prioritize involve stakeholders affected by those decisions
- comparing how different kinds of STI can address different challenges, rather than focusing on advancing specific types of STI
- maintaining a diverse and balanced portfolio of research and innovation investments

Design accountable initiatives that strengthen STI governance and support open and inclusive processes of deliberation and prioritization.

This includes:

- setting up a global platform observatory to conduct regular surveys of global R&D, its diversity, inclusion, scale, locations, purposes and impacts
- bringing together constellations of funders to align how they support SDG priorities
- creating global funding pools to maximise the impact on global challenges

Empower stakeholders to form different interpretations of what counts as SDG-related STI.

This includes:

- developing and maintaining user-friendly and open analytical tools in collaboration with policymakers and civil society organizations
- increasing funding for national data and statistical systems
- developing STI databases to better capture activities in social sciences, applied fields, diverse languages and in lower-income countries

REPORT : **OVERVIEW**

REPORT : OVERVIEW

Adopted by the United Nations in 2015, the Sustainable Development Goals (SDGs) offer a globally shared opportunity to change the directions of science, technology and innovation (STI) to contribute to a better and more sustainable future for everyone.

STI can help address many SDG challenges, for example, by increasing access to safe and nutritious food, improving per capita economic growth, or enhancing access to transport systems. However, in doing so, STI can also undermine progress towards some of the goals, for example, through carbon emissions or the pollution of water basins.

Our research has highlighted that current STI funding and prioritization are poorly contributing to achieving the globally agreed goals. Since STI funding and prioritization are largely driven by the values and interests of a few companies, governments and financial institutions, these decisions often serve the needs of the most influential and privileged, and may not address pressing SDG challenges.

India, for example, is a lower-middle income country (LMIC) that faces major challenges related to several SDGs: SDG 2 (Zero hunger), SDG 5 (Gender equality), SDG 6 (Clean water and sanitation), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable cities and communities), SDG 14 (Life below water) and SDG 15 (Life on land). However, besides SDG6, it prioritizes research only on SDG 7 (Affordable and clean energy) and SDG 12 (Responsible consumption and production). Evidently, there is a major disconnect between the problems it faces and the research it prioritizes.

Globally, in high-income countries (HICs), upper-middle income countries (UMICs) and LMICs such as India, between 60% and 80% of publications in the Web of Science (WoS) and between 95% and 98% of patented inventions are unrelated to the SDGs. In low-income countries (LICs), where most SDG challenges are worst, there is a higher share of SDG-related research (60%-80% is related to the SDGs). However, these countries produce an extremely low proportion of world research (0.2%) and patented inventions (0.02%).

So how can we steer STI activities towards solving, rather than exacerbating, SDG challenges? Just doing more R&D will not contribute to achieving the SDGs. Depending on the directions of the associated STI, it can, in fact, undermine progress towards them.

We need to change the directions of STI in order to address the glaring misalignment between research and innovation priorities and the SDGs. This is the only way to achieve our SDG targets and build a better, more sustainable world.

Our approach

Determining how to invest in research and development for the SDGs is not a simple task. There is no single definitive perspective or STI direction for addressing any particular SDG. Each SDG challenge can be viewed differently, according to diverse and plural understandings, values, interests and STI priorities.

To help understand and better address the challenges of investing in STI for the SDGs, while embracing the complex relationship between STI and the SDGs, we carried out a major global study to determine how and to what extent the world's STI priorities are aligned with the goals (Figure 0.1).

- We analysed scientific publications and patents data to gather quantitative information about global research and innovation priorities, and how these align with SDG challenges.
- We conducted a global survey of stakeholders to explore views about what types of STI are needed in the future to help achieve the SDGs. This allowed us to consider the alignment between current and desired STI priorities.
- We interviewed local STI users, including fishers, farmers and researchers, to explore how different actors, each with their own priorities, are shaping local STI pathways to tackle specific sustainability challenges. We then appraised stakeholders' views about how far each pathway aligns with sustainable development objectives.
- We produced data, mappings and case studies to gain a better understanding of STI priorities and to illustrate how such evidence and methods could be used in other contexts, according to plural interpretations of SDG challenges and STI pathways.

By combining these analyses, we gained deep insights into the way that particular STI priorities emerge both locally and globally, and how STI can be steered to improve alignment with the SDGs. Our results can help policymakers, research funders, academics, international organizations (INGOs) and aid organizations to make informed decisions about investing in research and innovation that will address the SDGs and ultimately create a positive impact on society.

Key findings

Problems of orientation and inequality

Current STI priorities in public and private R&D organizations are poorly aligned with the SDGs. Our analyses of SDG-related publications and patented inventions reveal that in HICs and UMICS – which dominate the global research agenda – just 20-40% of all published research, and only 2-5% of all patented inventions, relate to the SDGs (Figure 0.2). Moreover, 60% of this research is related to just one goal: SDG 3 (Good health and well-being), with a focus on diseases that are most prevalent in richer HICs and UMICs.

Meanwhile, in LICs (which face the most significant SDG challenges), 60-80% of research and 9% of inventions relate to the SDGs. However, their influence on the global research agenda is minimal, as these countries produce just 0.2% of all WoS research and 0.02% of all patented inventions (Figure 0.3).

To address local SDG challenges and inform policy decisions, countries need to build their own research and problem-solving capabilities. However, there are few opportunities for knowledge transfer and capacity-building in LMICs and LICs. This is due to the tiny fraction of academic research that is conducted in, or in collaboration with, these countries and the high proportion of research in these countries that relies on collaborations with HICs (Table 0.1). Where research collaborations between lower-income and higher-income countries exist, HIC research organizations tend to direct STI funding towards issues that they believe are, or should be, priorities in LICs.

Figure 0.1 / The STRINGS project: a multi-method, multidisciplinary study

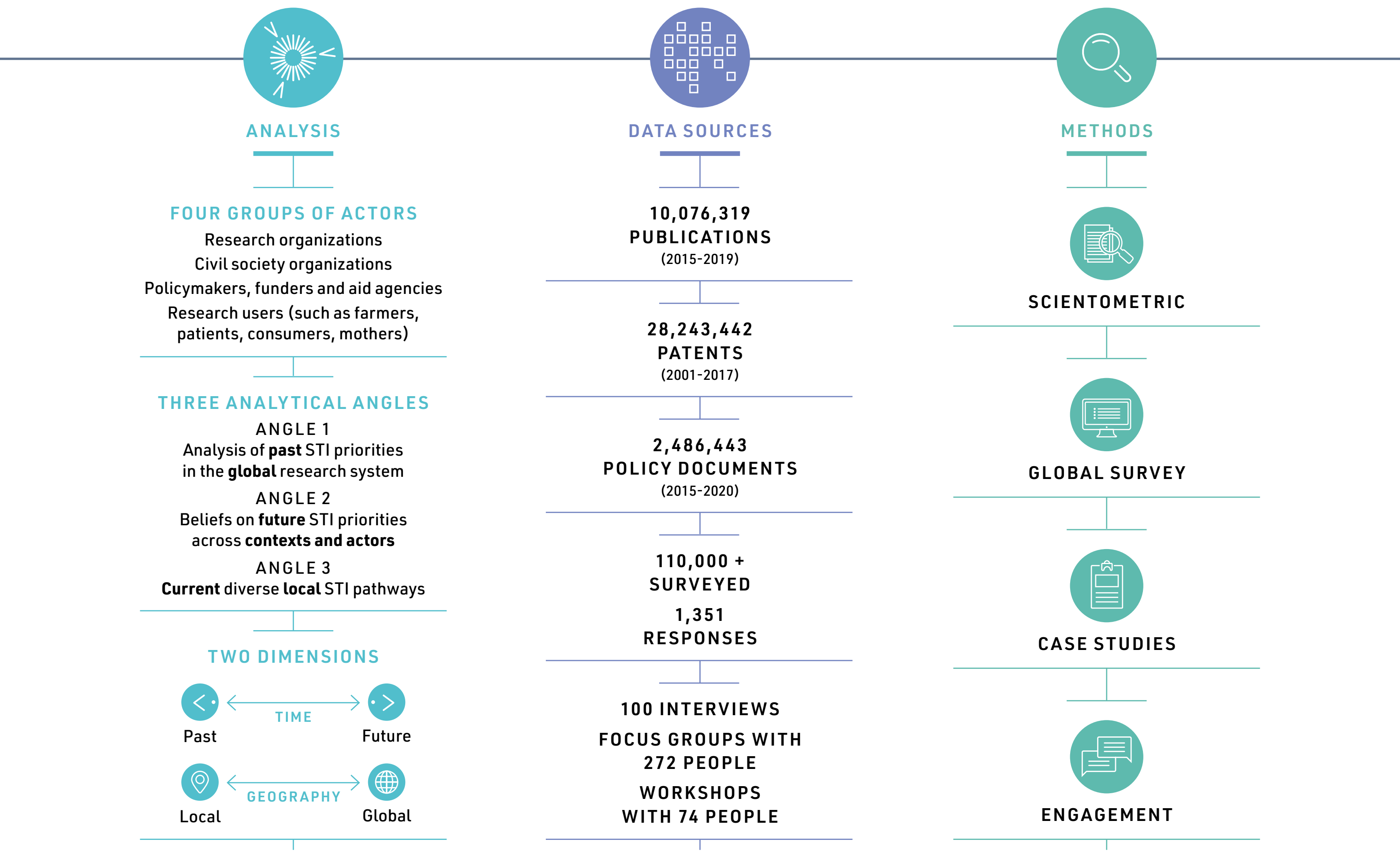
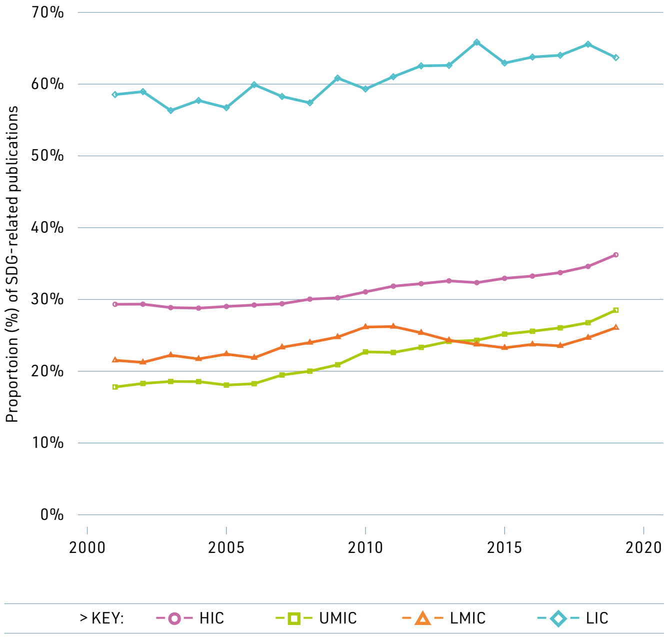


Figure 0.2 / SDG-related publications in different country income groups (2001-2019)



The graph shows the proportion of publications that relate to any of the SDGs (1-16). It is based on the total number of publications in countries in each of the four World Bank income groups (2021 definition): high-income countries (HIC); upper-middle-income countries (UMIC); lower-middle-income countries (LMIC); low-income countries (LIC). Based on strict interpretation of SDG-related research. See Appendix 2, Figure A.2.1 for a figure based on the loose interpretation.

See Chapter 4 of the main report for more details.

Figures based on Web of Science data. Centre for Science and Technology Studies (CWTS) version.

Problems of focus and knowledge siloes

We discovered that there are fewer efforts to address complex underlying social issues, such as deprivation, inequality and conflict (related to SDGs 1, 4, 5, 10 and 16), than to develop technological responses to more immediate challenges, such as access to energy (SDG 7) or drugs (SDG 3). And there is little research that interrogates how technological responses relate to these complex underlying social issues (Figure 0.4). For instance, research related to building STI capabilities (such as in SDG 9) is carried out more frequently in connection to research on technological solutions related to SDG 7 (Affordable and clean energy), SDG 8 (Decent work and economic growth) and SDG 12 (Responsible production and consumption (SDG12) than it is to the complex underlying social issues, such as SDG 4 (Quality education), SDG 10 (Reduced inequalities), SDG 1 (No poverty) or SDG 16 (Peace, justice and strong institutions).

Focusing mainly on technological interventions in isolation undermines our capacity to investigate synergies and tensions between STI and several SDGs.

Table 0.1a / Collaborative SDG-related publications within and between each country group (as a percentage of global collaborations)

COUNTRY GROUPS	HIC	UMIC	LMIC	LIC
HIC	66.32%			
UMIC	3.65%	18.69%		
LMIC	1.19%	0.28%	3.78%	
LIC	0.24%	0.04%	0.06%	0.30%
TOTAL	3,121,395 (71.40%)	990,797 (22.66%)	231,707 (5.30%)	27,607 (0.63%)

Table 0.1b / Collaborative SDG-related publications within and between each country group (as a percentage of a country group's total collaborations)

COUNTRY GROUPS	HIC	UMIC	LMIC	LIC
HIC	92.89%	5.12%	1.67%	0.33%
UMIC	16.12%	82.48%	1.23%	0.18%
LMIC	22.43%	5.25%	71.27%	1.04%
LIC	37.65%	6.31%	8.75%	47.29%

1a: This shows what proportion of all global collaborative publications occurred within (diagonal) and between (off the diagonal) country groups. For example, a publication co-authored by authors in the USA and the UK (both HICs) would contribute to the percentage in the top left cell. A publication co-authored by authors in the USA and Brazil (between HIC and UMIC) would contribute to the second row of the first column). The sum of all cells equals 100%.

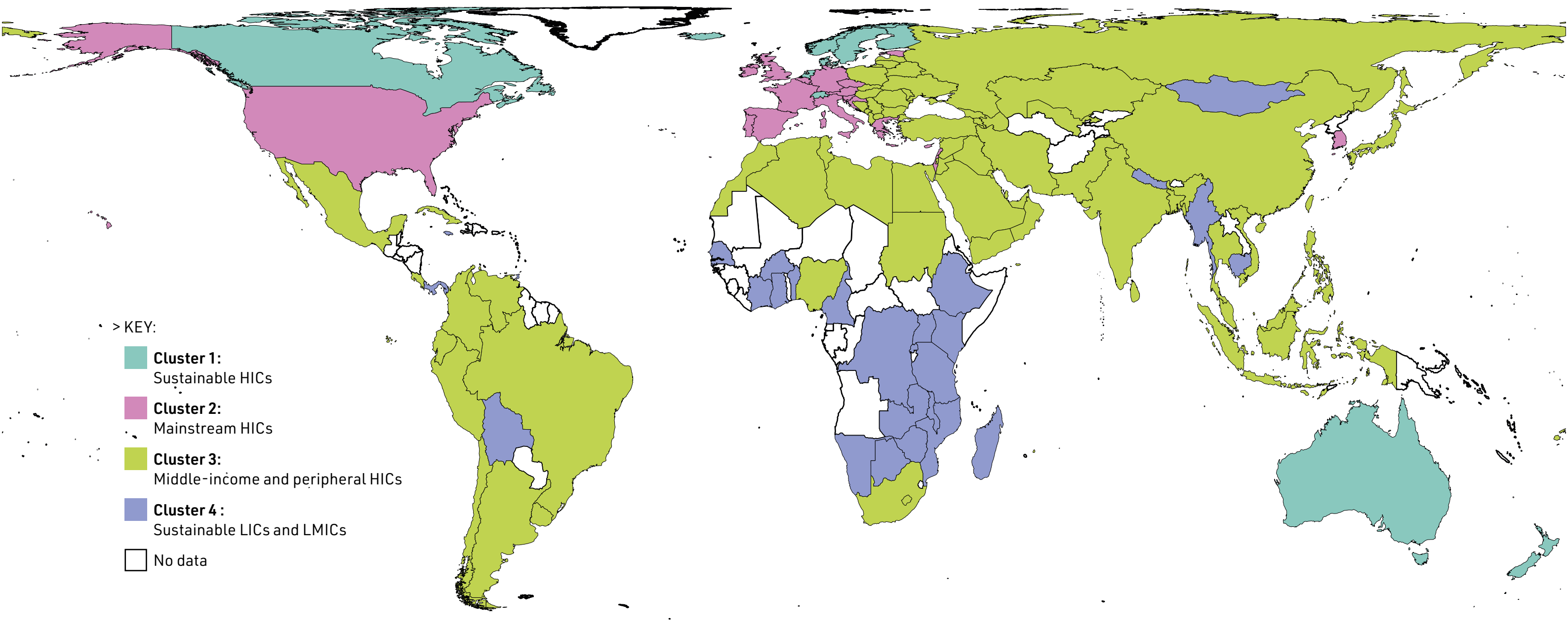
1b: This shows what proportion of the collaborations within each country group occurred within and between country groups. For example, the first row shows the country groups involved in all collaborative research undertaken by HIC. The row total sums to 100%.

See Chapter 4 of the main report for more details.

HIC: High-income countries; UMIC: Upper-middle-income countries; LMIC: Lower-middle-income countries; LIC: Low-income countries.

Figures are based on WoS data (CWTS version), 2015-19.

Figure 0.3 / Country clusters based on publications and research capacity



Cluster 1

SUSTAINABLE HICs

This group comprises the most research-intensive HICs.

Publications per capita:	3.6
2021 SDG Index ranking*:	80.2
Proportion of SDG-related publications	38%

They have an ***above average*** share of publications related to:

- **SDG 4** (Quality education)
- **SDG 9** (Industry, innovation and infrastructure)
- **SDG 10** (Reduced inequalities)
- **SDG 12** (Responsible consumption and production)
- **SDG 13** (Climate action)
- **SDG 14** (Life below water)

Cluster 2

MAINSTREAM HICs

Countries in this group, with the exception of Lebanon, are all HICs.

Publications per capita:	1.79
2021 SDG Index ranking*:	78.6
Proportion of SDG-related publications	32%

They have an ***above average*** share of publications related to:

- **SDG 4** (Quality education)
- **SDG 8** (Decent work and economic growth)
- **SDG 9** (Industry, innovation and infrastructure)
- **SDG 10** (Reduced inequalities)

They have a ***well below average*** share of publications on the environmental SDGs.

Cluster 3

MIDDLE-INCOME AND PERIPHERAL HICs

This is the largest group, combining those UMICs (47%) and HICs (26%) with a below average number of publications per capita, alongside those LMICs (22%) with a low number of publications per capita.

Publications per capita:	0.3
2021 SDG Index ranking*:	70
Proportion of SDG-related publications	29.5%

Most countries in this group have a ***high*** share of publications related to:

- **SDG 6** (Clean water and sanitation)
- **SDG 7** (Affordable and clean energy)

UMICs and HICs in this cluster also have a ***high*** share of publications related to:

- **SDG 8** (Decent work and economic growth)
- **SDG 9** (Industry, innovation and infrastructure)
- **SDG 12** (Responsible consumption and production)

Cluster 4

SUSTAINABLE LICs and LMICs

This group is composed mainly of LMICs (52%) and LICs (30%).

Publications per capita:	0.06
2021 SDG Index ranking*:	58.7
Proportion of SDG-related publications	LMICs 55% LICs 73%

They have a ***high*** share, particularly in LICs, of publications related to:

- **SDG 1** (No poverty)
- **SDG 2** (Zero hunger)
- **SDG 3** (Good health and well-being)
- **SDG 5** (Gender equality)
- **SDG 6** (Clean water and sanitation)
- **SDG 16** (Peace, justice and strong institutions)

They have an ***above average*** share, particularly in LMICs, of publications related to environmental SDGs.

*The SDG Index measures each country's progress towards achieving the SDGs

Notes on the map: Each colour identifies one cluster of similar countries. A strict interpretation of SDG-related research was used. Countries with less than 500 total SDG-related publications between 2015-19 were not counted because their share of publications per SDG is extremely volatile.

See Chapter 4 of the main report for more details.

Figures based on Web of Science data (CWTS version).

Figure 0.4 / Research synergies across SDGs

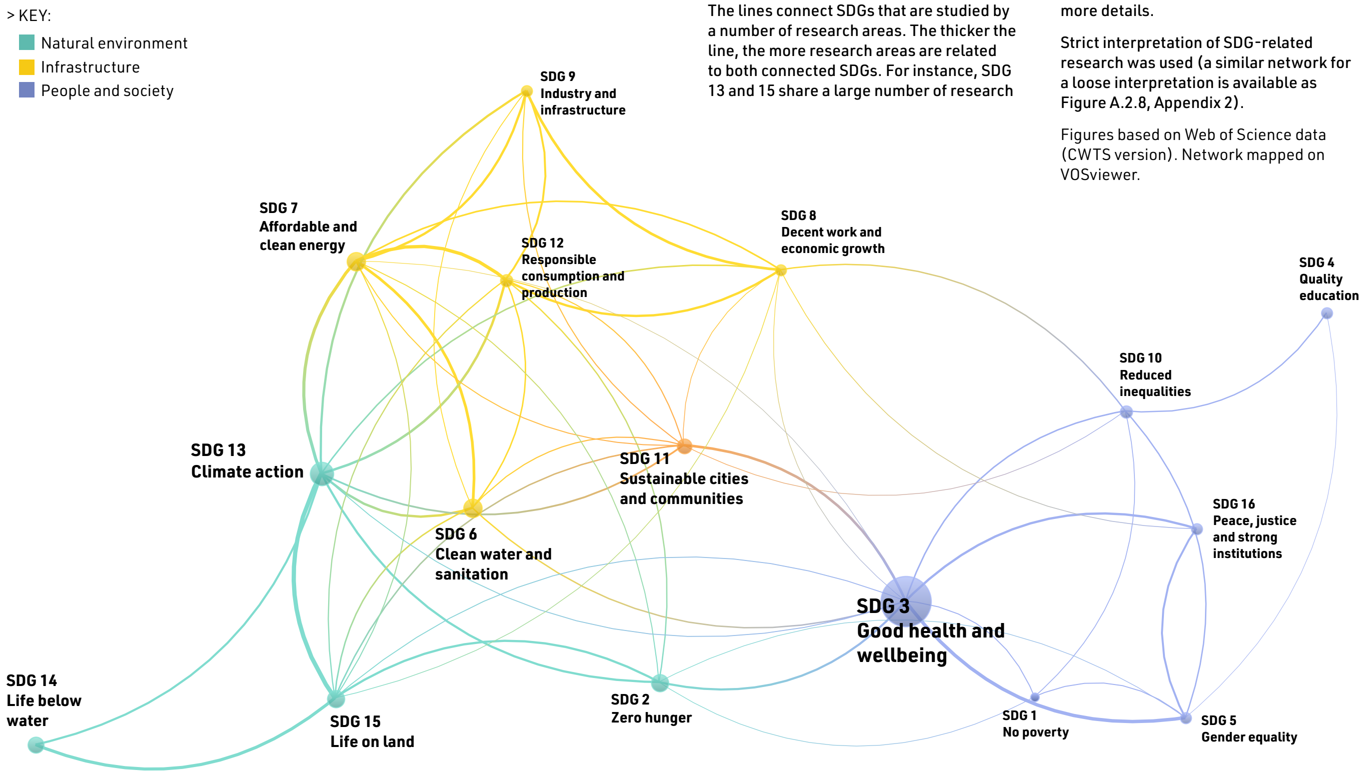
Each node identifies one SDG (the size of the node is proportional to the number of publications relating to that SDG). Each colour identifies one cluster of SDGs.

The lines connect SDGs that are studied by a number of research areas. The thicker the line, the more research areas are related to both connected SDGs. For instance, SDG 13 and 15 share a large number of research areas and publications, while SDG 4 shares only a small number of research areas and publications with SDG 10.

See Chapter 4 of the main report for more details.

Strict interpretation of SDG-related research was used (a similar network for a loose interpretation is available as Figure A.2.8, Appendix 2).

Figures based on Web of Science data (CWTS version). Network mapped on VOSviewer.



GREEN

A cluster of SDGs related to: the natural environment

SDGs 13 Climate action
SDG 14 Life below water
SDG 15 Life on land

These are connected to the lilac cluster via:
SDG 2 Zero hunger

YELLOW

A cluster of SDGs related to: economic growth, infrastructures and technical solutions

SDG 6 Clean water and sanitation
SDG 7 Affordable and clean energy
SDG 8 Decent work and economic growth
SDG 9 Industry, innovation and infrastructure
SDG 12 Responsible consumption and production

LILAC

A cluster of SDGs mainly related to: people and society

SDG 1 No poverty
SDG 4 Quality education
SDG 5 Gender equality
SDG 10 Reduced inequalities
SDG 16 Peace, justice and strong institutions

And the main bridge to the other clusters:
SDG 3 (Good health)

SDG 11 (Sustainable cities and communities) connects to research in all three clusters.

> KEY: **Sustainable Development Goals**

- **SDG 1** No poverty
- **SDG 2** Zero hunger
- **SDG 3** Good health and well-being
- **SDG 4** Quality education
- **SDG 5** Gender equality
- **SDG 6** Clean water and sanitation
- **SDG 7** Affordable and clean energy
- **SDG 8** Decent work and economic growth
- **SDG 9** Industry, innovation and infrastructure
- **SDG 10** Reducing inequality
- **SDG 11** Sustainable cities and communities
- **SDG 12** Responsible consumption and production
- **SDG 13** Climate action
- **SDG 14** Life below water
- **SDG 15** Life on land
- **SDG 16** Peace, justice, and strong institutions
- **SDG 17** Partnerships for the Goals

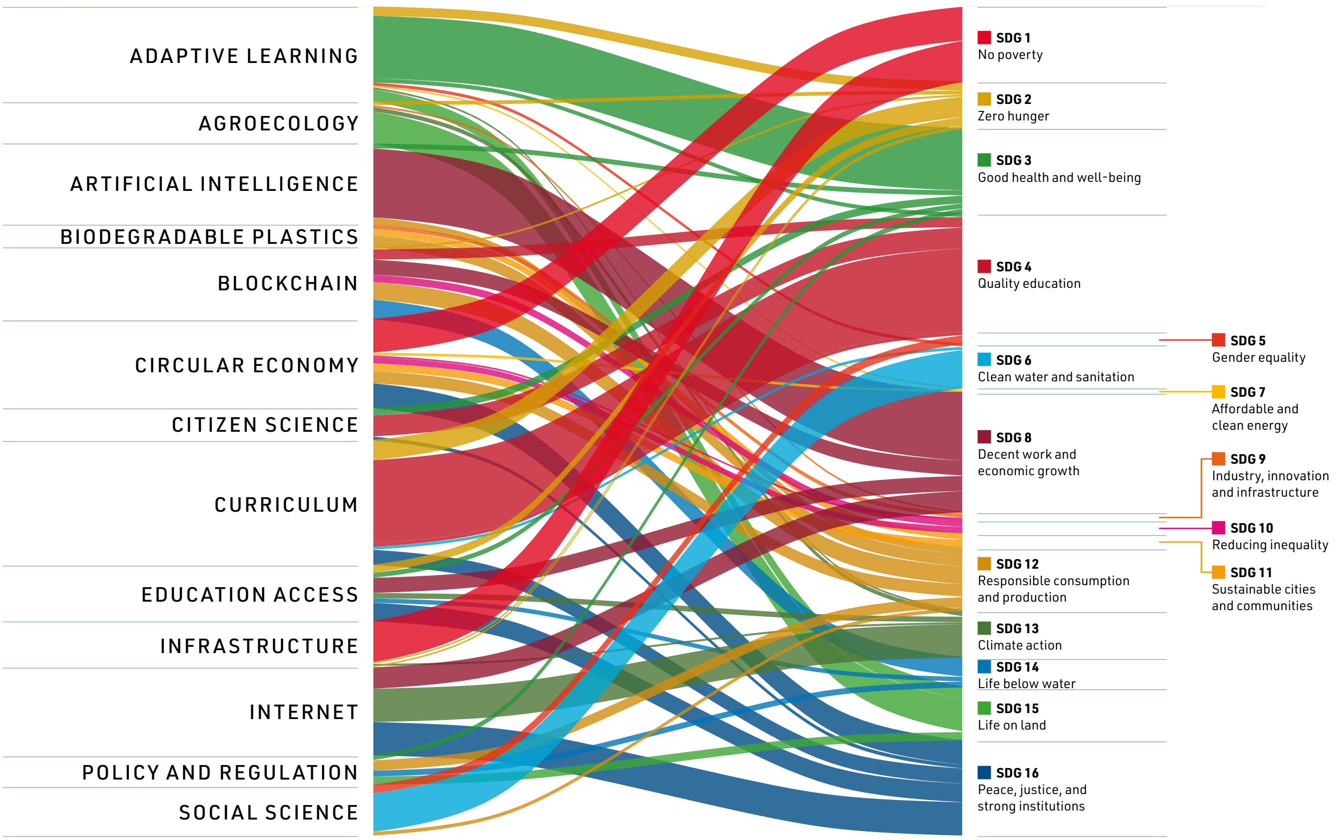
Our global survey (Chapter 7) confirmed that the development of one STI may positively support one SDG target but negatively affect the progress towards another (Figure 0.5). For example, blockchain technologies can not only speed up access to financial services (SDG 8.10), improve waste management (SDG 12.5) and address marine pollution (SDG 14.1), but can also support trafficking and sexual exploitation (negatively impacting on SDG 5.2) and is energy intensive (with a negative impact on SDG 12.2).

Focusing on technological interventions in isolation is also unlikely to deal with the underlying issues behind many SDG challenges. For instance, despite the fact that education and governance are important in tackling neglected diseases such as Chagas, in our Argentina case study, we found that research related to SDG 4 (Quality education) and SDG 16 (Peace, justice and strong institutions) was infrequently carried out in connection with research on SDG 3 (Good health and well-being). In our Kenya case study, we found that access to resources below water and on land (SDGs 14 and 15) is deeply connected to peace, justice and institutions (SDG 16), but research on those SDGs at the global level is rarely connected (Figure 0.4).

Social science research is needed to complement research on technical solutions so as to better address many of the underlying social issues. Isolating social research from research relating to the environment, infrastructure and growth SDGs creates 'social blindspots' in the research agenda. And it prevents us from understanding the extent to which technical research can address the underlying social issues – or potentially not exacerbate them.

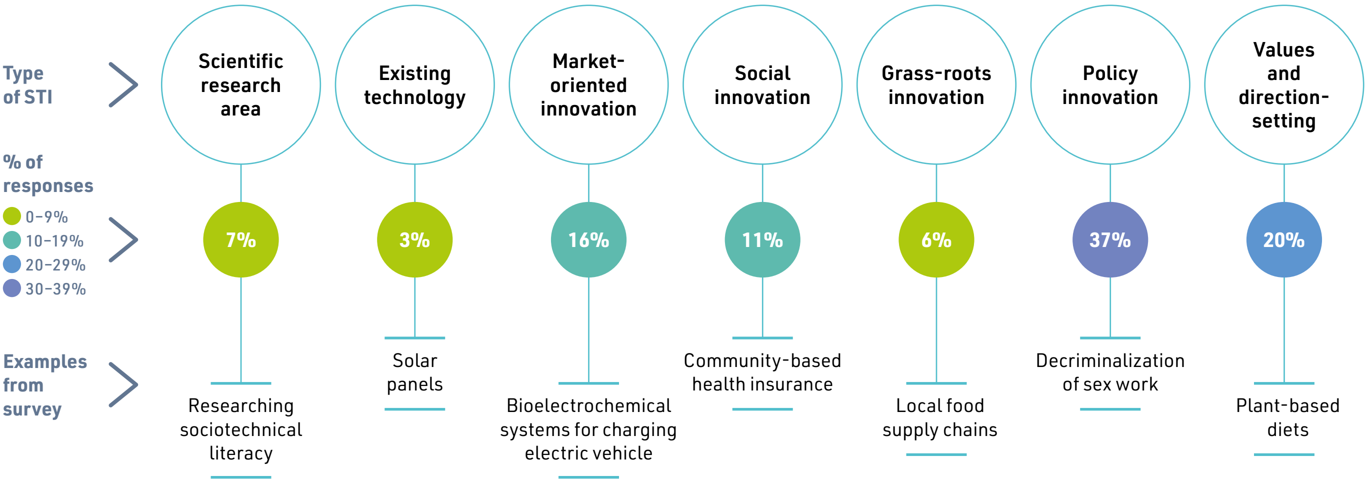
Our analyses show that SDG-related research on underlying social issues is more multidisciplinary and more likely to be used in policy and reported in the media than research on energy or on climate change. Despite this, and the fact that it is at least as highly rated by standard quality metrics as the average WoS publication, it does not benefit from the same level of collaborations across countries and is the least funded area of research (Chapter 4).

Figure 0.5 / STI synergies across the SDGs



Our survey (see Chapter 7 of the main report) identified 13 STI areas as synergistic – linking to three or more SDGs. The figure shows the links to various SDGs for these STI areas. Line colours reflect a specific STI area. Line thickness is proportional to the number of survey responses that identified a specific STI-SDG link. Figures based on our Delphi survey data.

Figure 0.6 / STI priorities identified in the STRINGS survey



We asked stakeholders to propose the types of STI they believe could help achieve the SDGs by 2030 (see Chapter 7 of the main report). The figure shows what percentage of survey responses suggested each type of STI, together with some examples of each type, drawn from the responses. For analysis purposes, we assigned only one STI type for each response. In practice, an activity can fit multiple innovation types. Figures based on our Delphi survey data.

The direction of current STI differs greatly from stakeholder priorities. Through our global survey (Chapter 7), we gathered a range of perspectives about the potential future contribution of STI towards the SDGs. Responses prioritized policy innovations (37%), social and grassroots innovations (11% and 6%, respectively), and values and direction-setting (20%), rather than the more conventional scientific research and market-oriented innovations (16%), which are currently the focus of a significant proportion of global STI (Figure 0.6).

Even scientists, researchers, and technology developers (who in total comprised 69% of survey respondents) believe that developments in traditional scientific research alone are not sufficient to achieve the SDGs. While the survey uncovered a wide diversity of opinions, there was more positive agreement about policy innovations than about the use of technologies. By focusing on scientific research and market-oriented technologies, existing STI overlooks other types of innovations that are crucial to address the complexity of the SDGs by 2030.

A problem of regional misalignment

Countries focus to a limited extent on research related to their major SDG challenges.

When countries specialize in research that is unrelated to their main sustainability challenges, there is a misalignment between research priorities and the SDGs. In Argentina, for example, major challenges exist in relation to SDG 9 (Industry, innovation and infrastructure), SDG 10 (Reducing inequality) and SDG 15 (Life on land). Despite this, besides SDG15, it prioritizes research on SDG 2 (Zero hunger), SDG 13 (Climate action), and SDG 14 (Life below water). Only SDG 15 appears in both lists (see Chapter 6).

Meanwhile, HICs – which have the most unsustainable consumption patterns, generate more CO_2 emissions and contribute the most to climate change – do not specialize in research on the major environmental challenges relating to SDG 12 (Responsible consumption and production), SDG 13 (Climate action) or SDG 15 (Life on land).

In both examples, the countries' research priorities are not aligned with their most pressing SDG challenges. This is the case for most SDGs (see Figure 0.7). In the few cases where countries specialize in research related to their biggest challenge, this is usually the result of past research specialization (in the case of LICs, often linked to foreign funding), rather than a realignment of priorities following changes in SDG challenges.

Figure 0.7 / Alignment between SDG challenges and SDG research

The charts show the relationship between SDG challenges (2008-2017) and SDG research priorities (2015-2019) for SDGs 2, 4, 6 and 13. See Chapter 6 of the main report for more details.

Countries are shown in different colours based on their income group.

The y-axis represents the research specialization of a country in a certain SDG (> 0 indicates that a country is relatively specialized in research related to that SDG. < 0 indicates less specialization in this area than the world average).

The x-axis represents SDG challenge scores. 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. Each dot indicates a country.

Figures based on Web of Science data (CWTS version) and on the SDG Index data.

> KEY
- High income
- Upper-Middle income
- Lower-Middle income
- Low income
- Linear regression
- 95% confidence interval

A problem of closing off relevant STI pathways

There is no singular, self-evident, 'most aligned' STI pathway, even for the most specific of SDG-related challenges. How pathways are prioritized depends on how a diverse set of individuals, organizations and stakeholders frame their values, interests and priorities.

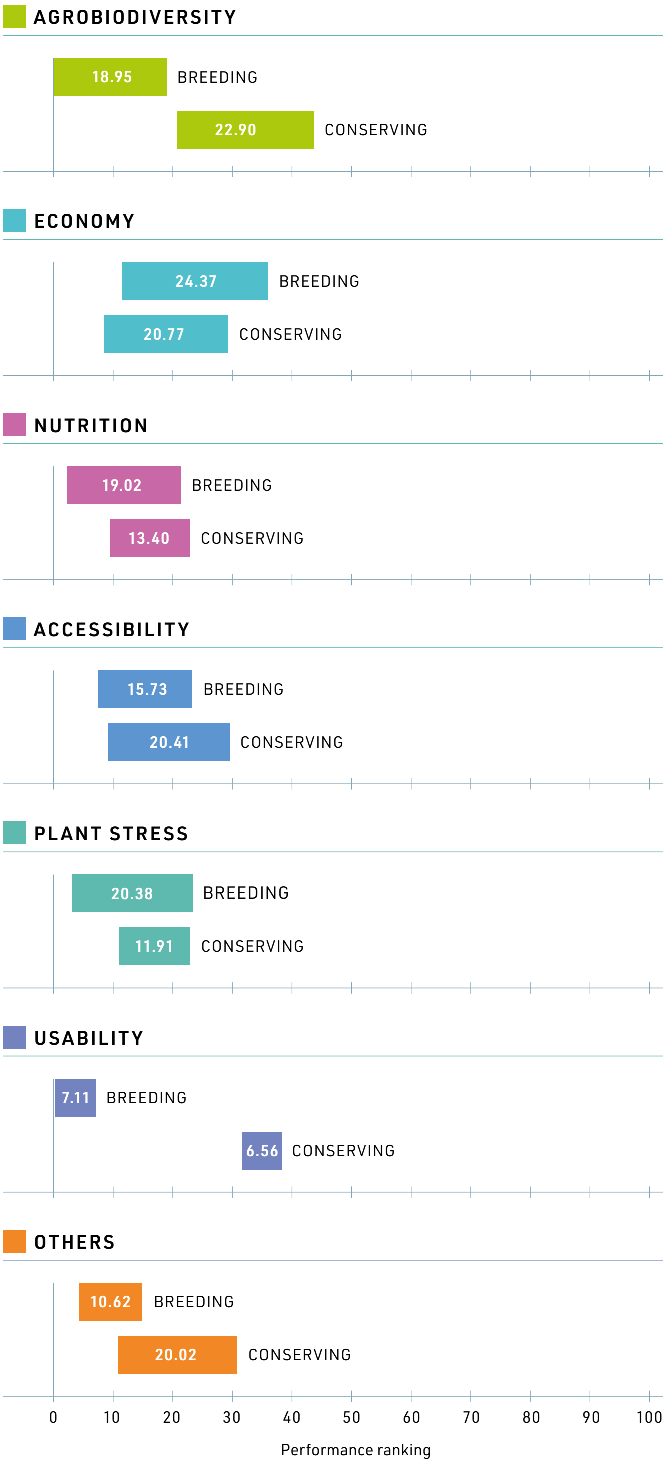
Our case studies (Chapter 8) illustrate how particular pathways can become dominant, sometimes closing down alternative ways to achieve the SDGs. In India, for example, we explored two distinct STI pathways to develop and access rice seed varieties that are resilient to the challenges of climate change: (1) breeding new seeds in laboratories, and (2) conserving and exchanging seeds from indigenous plant varieties. To what extent each pathway is prioritized depends on the actors involved and their influence.

While many relevant STI pathways exist, a few individuals, organizations and stakeholders tend to be in control of STI decisions and one (or a few) pathways will dominate in terms of funding and policy attention, even when they are not the most supported by wider society. This is the case in the Indian case study. There was strong agreement among the various stakeholders involved in our research that the conservation pathway (which involved local civil society organizations, seed champions and seed conservationists) was the better performing in terms of agrobiodiversity and usability (Figure 0.8). However, unlike the breeding pathway (which involved government institutions, universities and private firms), the conservation pathway has received little support or investment from public institutions.

Likewise, our case studies in Argentina, India and Kenya illustrate how certain pathways are more successful than others in aligning diverse STI pathways with priorities and challenges within the SDGs (Chapter 9).

Our analysis has revealed several opportunities for policymakers, national and global funders and NGOs to steer STI activities towards solving, rather than exacerbating SDG challenges.

Figure 0.8 / Appraisals of seed pathways in Odisha, India



We gathered stakeholders' views about how well two STI pathways in India could address various sustainability issues (see Chapter 9 of the main report). Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway by different groups of participants in our case study research. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Ways forward: our recommendations

For STI to make a substantial contribution to address SDG-related challenges within regions, nations or at a global level, we have provided recommendations and tools to inform effective policy actions and encourage active and inclusive debates.

Increase funding for SDG-related research and innovation and improve alignment between STI portfolios and SDG priorities

Research funders, aid organizations involved in research funding, INGOs and the academic community should:

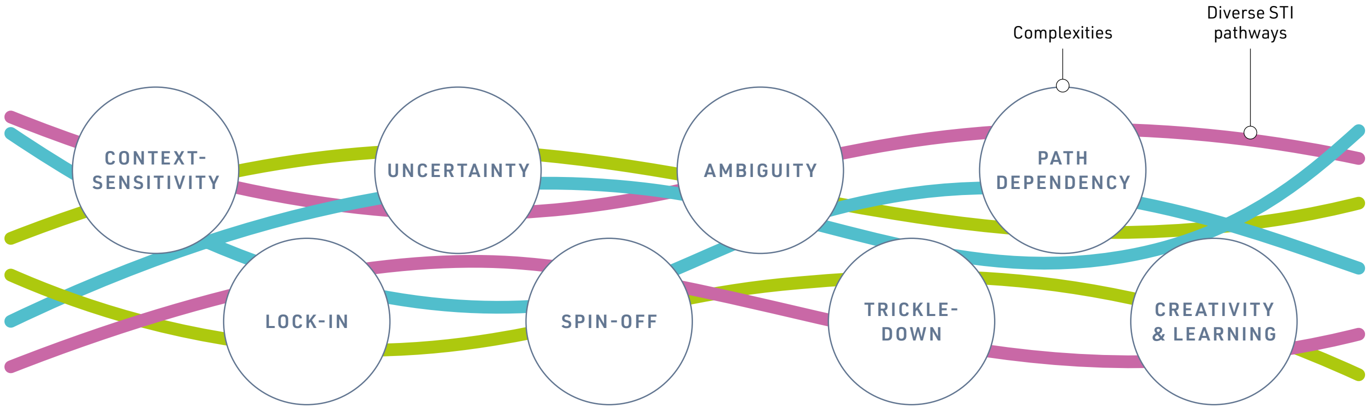
Ensure STI funding and research is directed towards SDG-related issues by:
- directing funding in HICs and UMICs with unsustainable consumption and production patterns towards research that addresses environmental issues
- ensuring that national and international funding frameworks support SDG-related research that involves a leading role for research organizations based in LICs
- regularly reviewing priorities for research funding based on consultations across different disciplines and sectors of society, in order to support shifting local and national sustainable development priorities
- overcoming historical and ingrained patterns of funding and responding to national and local challenges to guide decisions in funding R&D portfolios
- enabling open and plural decision-making, including identifying and implementing funding priorities through participatory processes with civil society organizations and research users

Increase funding of research into underlying issues of deprivation, inequalities and conflict by:
- increasing funding for research and innovation that focus on the complex social, historical and political determinants of sustainability, related to inequalities and conflicts
- steering public funding to complement, rather than follow, private funding directed at technological solutions

Focus on research areas that connect to several SDGs by:
- funding more research that explicitly investigates tensions and synergies between different aspects of sustainability
- connecting research on deep-seated issues of deprivation, inequalities and conflict with research on more technical solutions

Involve a more diverse set of actors in research funding decisions by:
- directly funding research institutes in LICs and including researchers and stakeholders from these regions in the research and decision-making processes
- ensuring that collaborative projects are equitable partnerships, thus creating more opportunities for equitable knowledge transfers and capacity-building
- including LIC researchers and stakeholders in the advisory and management committees of funders, to ensure their views are considered in planning, defining and evaluating research agendas

Figure 0.9 / Addressing complexities through deliberate diversification



A diverse research or innovation portfolio offers a more robust approach than conventional policy appraisals (see Chapter 10 of the main report).

Adopt a more holistic approach to research funding design and evaluation by:

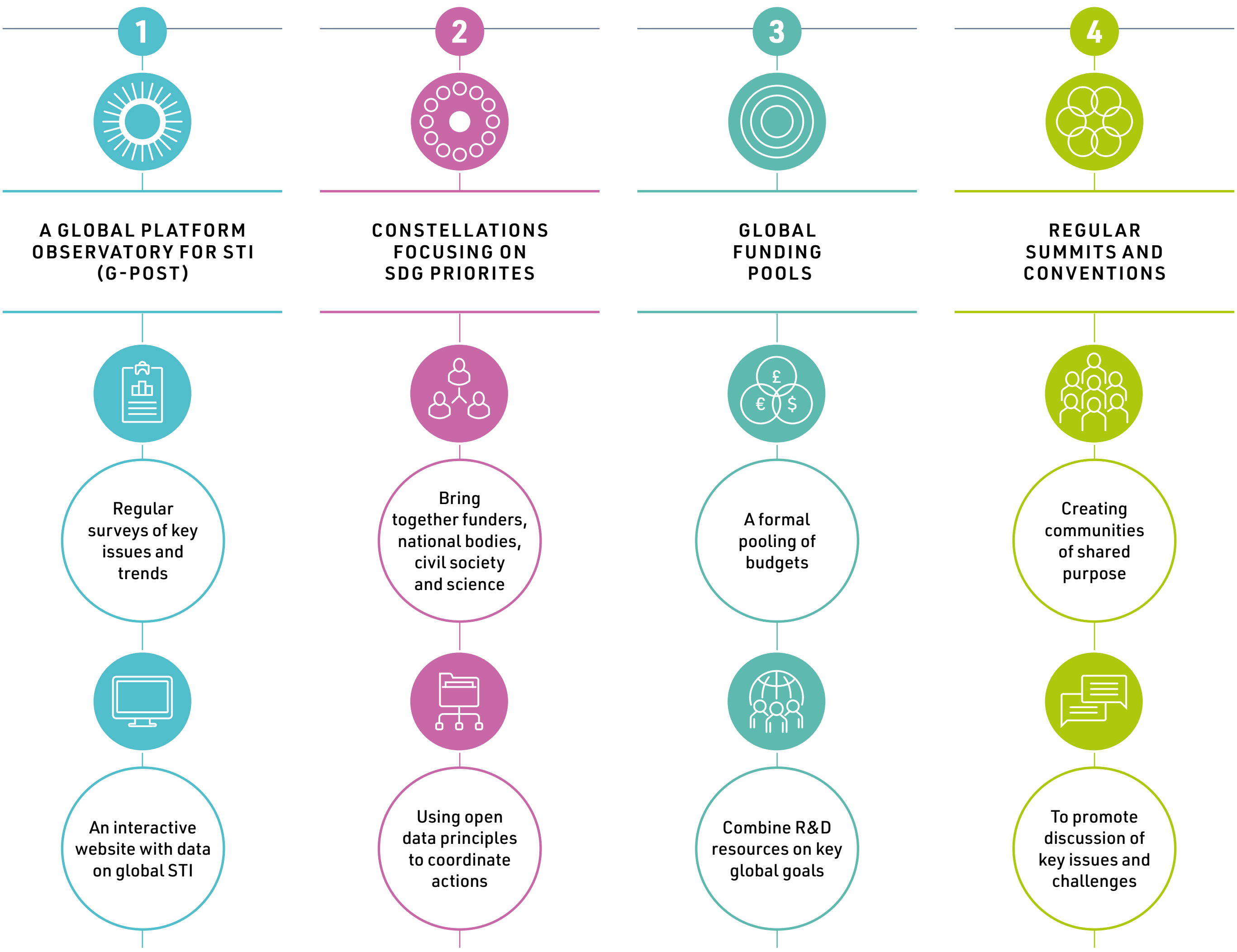
- providing greater support for interdisciplinary and transdisciplinary research, to improve the understanding of synergies and tensions between socioeconomic, environmental and infrastructure-related SDGs
- increasing the involvement of users from across policy, industry and civil society – including marginalized knowledge producers such as small farmers, water conservationists and informal organizations – in the design, conduct and evaluation of formal research and social innovations, to address the complex, interwoven challenges of the SDGs
- adopting research evaluation measures that promote and value the production of knowledge in multiple arenas beyond formal science and technology, including social innovations and 'indigenous' knowledge
- considering the positive and negative impacts of research on society as perceived by different stakeholders

Promote a rich diversity of STI pathways to address the diverse SDG challenges (Figure 0.9)

Policymakers, governments, civil society and aid organizations should:

- Encourage debates involving and including a diverse set of actors to help steer STI in more balanced ways.
- Ensure decisions about which STI pathways to prioritize involve the stakeholders affected by those decisions, to allow more democratic representation of a wide range of values and interests around different SDGs.

Figure 0.10 / How global governance of research and development can support the SDGs



- Put in place processes and mechanisms, such as public consultations or talking with diverse actors, to question how STI pathways are analysed from diverse perspectives.

Research funders and aid organizations involved in research funding should:

- Compare how different STIs address different challenges, rather than focusing on advancing specific STIs.
- Maintain a diverse and balanced portfolio of R&D to address challenges, particularly those that are sensitive to different contexts.
- Promote diversity in research and innovation to counterbalance specific R&D interests that might emphasize singular directions.
- Ensure transparent communication of research findings, participatory involvement, open accountability and democratic governance.

Design accountable initiatives that strengthen STI governance and support open and inclusive processes of deliberation and prioritization (Figure 0.10)

Policymakers, INGOs, civil society organizations and aid agencies should:

- Establish a global platform observatory to conduct regular surveys of international R&D, its diversity, inclusion, scale, locations, purposes and impacts (the platform would work closely with the International Science Council, the International Network for Government Science Advice, OECD, UNESCO, as well as civil society, business, universities and other users of STI).
- Bring together a 'constellation' of funders, civil society, business, universities and science policy decision makers to replicate the type of exercises undertaken by the STRINGS project, to align research to potential challenges by using open data, open coordination and engagement of users.
- Organize regular gatherings to create communities of shared purpose and understanding, as well as encouraging wider social deliberation over the steering of policy.

Research funders should:

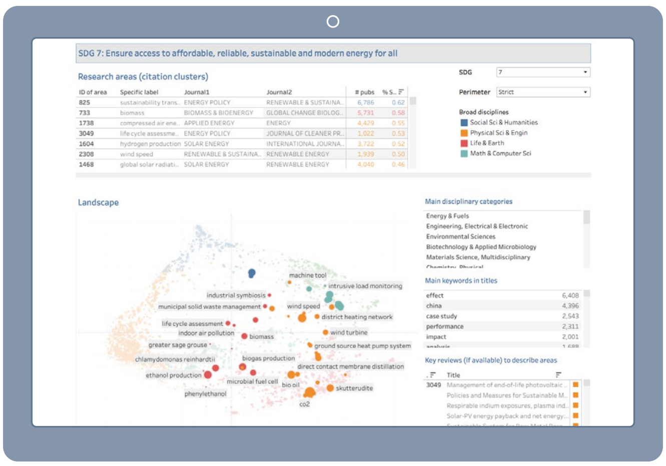
- Establish formal global funding pools to combine R&D resources on key global goals established through open and inclusive deliberations in the global platform observatory.

Empower stakeholders to express different interpretations of what counts as SDG-related STI

Research funders, the academic community and aid organizations involved in research funding should:

- Develop and maintain open analytical tools (such as visualization platforms – see Chapter 12) that can be adapted and scrutinized by users in collaboration with policymakers and civil society organizations. The tools should enable different stakeholders to decide which research and innovation areas are most appropriate for addressing an SDG, according to their contexts, needs, values and aspirations (Figure 0.11).
- Develop databases to capture STI activities in social sciences, in applied fields and in LIC and LMICs. This includes publications in diverse languages; research outputs other than publications and patents; adaptations of existing technologies; and incremental innovations, social innovations, policy innovations and grassroots innovations outside the formal sector.
- Improve the internal consistency, comparability and overall quality of data, especially in LICs and LMICs. For example, among the 388,792 data points to measure progress in the SDGs over 2000-2021 for 193 countries (Sachs et al. 2021), 221,426 are missing (57%); and these are mainly from LICs and LMICs.

Figure 0.11 / Interactive visualization of the research landscape for SDG 7 (affordable and clean energy)



The STRINGS interactive tool (see Chapter 12 of the main report) enables users to create their own mapping of scientific research to the SDGs. Users can adjust settings to identify research areas that are potentially relevant for each SDG.

SECTION 1

INTRODUCTION

SETTING THE SCENE

The Sustainable Development Goals

The 17 United Nations Sustainable Development Goals (SDGs) are a comprehensive, internationally agreed set of objectives, adopted by the United Nations General Assembly in 2015 as part of the United Nations 2030 Agenda for Sustainable Development.

The goals recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. They encompass 169 targets and 231 indicators of progress.

SDGs

Further information about the Sustainable Development Goals can be found at: **https://www.undp.org/sustainable-development-goals**

Science, technology and innovation

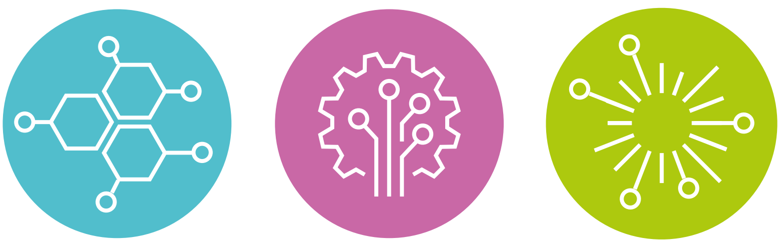
The 2030 Agenda acknowledges that science, technology and innovation (STI) are vital drivers in enabling the transformation towards prosperous, inclusive and environmentally sustainable economies.

Science refers to the production of knowledge of all kinds.

Technology is the combination of knowledge, practices and tools used to produce any product or service.

Innovations are new or improved products or processes, which may be market-oriented or may involve administrative, legal, regulatory and policy instruments or wider social, cultural or behavioural change.

STI



SCIENCE TECHNOLOGY INNOVATION

FREQUENTLY USED TERMS

The following words and phrases are used frequently in the report. Below we explain what we mean by these terms, how we use them in the report, and how they relate to each other.

Alignment

The central focus of this research is on the alignment between science, technology and innovation (STI) and the Sustainable Development Goals (SDGs): that is, how well STI pathways offer responses to specific SDG-related challenges. The objective of STI governance and research funding is to understand which STI pathways are most strongly aligned with which SDG challenges.

The report defines alignment using different methods and lenses of analysis across different chapters. These approaches offer different ways to think about alignment.

Directionality

Directionality refers to questions, issues and implications around the orientation of science, technology and broader social innovations. A focus on directionality switches the attention of STI governance from 'how fast?', 'how much?', and 'what is the risk?' towards questions such as 'which way?', 'who decides?' and 'why?'.

By considering which understandings to privilege, whose interests to prioritize, what values matter, and how to hold influential interests to account, it is possible to envisage alternative STI pathways, beyond those that promote mainstream science or economic growth.

Diversity

The report emphasizes the importance of diversity in responses to SDG challenges. In this context, diversity refers not only to the variety of STI pathways and directions pursued, but also to how disparate they are from each other and the balance of resource allocations between them.

Heuristic

A method of learning or problem-solving that allows people to discover things themselves and learn from their own experiences. In this report, we propose different heuristics to study and interpret the relations between STI and the SDGs.

Mappings

We map STI to a given SDG by identifying the research areas and inventions that are related to that particular goal. Different stakeholders have different understandings of which research areas and innovations are relevant. As a result, a mapping of STI to SDGs may depend on the specific contexts, perspectives and values of the analyst or stakeholder conducting the analysis. Therefore, there can be multiple meaningful and legitimate mappings of STI to SDGs.

Plurality

In this report, plurality refers to the vast worldwide array of interests, values and understandings that relate both to STI and to the SDGs themselves. For example, the SDGs encompass multiple challenges, each of which can be understood from a range of perspectives. And each STI pathway to address the goals may also be understood and evaluated in a variety of different ways.

SDGs

The 17 Sustainable Development Goals (SDGs) are at the heart of the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015. The 17 goals are shown on page 27.

SDG targets

The United Nations published 169 targets for the SDGs in July 2017. Each goal typically has between eight and twelve targets.

The targets are either 'outcome' targets (circumstances to be attained) or 'means of implementation' targets. The latter targets were introduced to address the concerns of some Member States about how the SDGs would be achieved.

SDG indicators

Each SDG target has between one and four SDG indicators to measure progress. There are 231 unique SDG indicators, with some belonging to more than one target. Most countries do not produce regular data for 97 of these indicators.

SDG-related research

To map and characterize SDG-related research, we devised a method to associate research areas with specific SDGs (see Chapter 4). This approach allows us to include publications that contribute to SDG-related research even if they do not use SDG-specific language in the title or abstract.

Steering

We use the term steering to refer to the use of policies and wider governance arrangements to guide STI priorities in particular directions.

Science, technology and innovation (STI)

STI refers to science, technology and wider social, grassroots and policy innovations. Further information is on page 27.

STI pathways

STI pathways are the alternative directions that can be taken by STI to address particular goals in specific real-world settings. An STI pathway involves not just technical solutions but also the governance mechanisms and socio-ecological circumstances that influence how decisions are made, what factors are prioritized, the use of resources, and who benefits from the solutions.

Synergies

We use the term synergies to describe the positive interactions between SDGs. For example, educational efforts for girls (SDG 4) in a low-income context could enhance maternal health outcomes (part of SDG 3) and also potentially contribute to poverty eradication (SDG 1), gender equality (SDG 5), and economic growth (SDG 8).

Tensions and trade-offs

Tensions and trade-offs refer to the negative interactions between SDGs. For example, intensive agriculture is a significant source of greenhouse gas emissions, so improvements in agricultural productivity and food production (SDG 2) can contribute negatively to climate change (SDG 13). Trade-offs imply a quantitative balance between priorities, while tensions are more complex.

Transdisciplinarity

Transdisciplinary research combines different kinds of knowledge from communities and stakeholders with academic and corporate research. By involving a greater plurality of perspectives, it helps produce understandings that are relevant and valid for diverse actors to address specific problems in particular contexts.

> CHAPTER 1

Aligning STI with the SDGs

An overview of the complex challenges

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OVERVIEW

This chapter introduces the key ideas at the heart of the STRINGS project. It explores:

- the importance of the Sustainable Development Goals (SDGs)
- the complex relationship between the SDGs and science, technology and innovation (STI)
- the challenge of how to better align STI activities with the goals

It then explains how the STRINGS project aims to tackle some of these complex issues by providing evidence and tools that help to illustrate and better understand misalignments between STI and the SDGs, and ultimately to inform the prioritizing of particular STI pathways in relation to specific SDG challenges.

Footnotes for this chapter are on page 35. A full list of references can be found on page 140.

Multiple directions for progress in STI

Despite much questioning and criticism, the importance of the SDGs in current world affairs is undeniable. Built on the foundations of decades of collective action, social mobilization and civic deliberation, their adoption was the culmination of a process that had been under way for nearly half a century.[1] With a scope and detail unmatched in any other single framework, the goals are unprecedented in their span across social, economic and environmental issues.

Global governance processes have now begun to wrestle in explicit, systematic and accountable ways with the perennial but neglected challenge of 'which way constitutes progress?' The framework of institutions, practices, discourses and metrics around sustainable development has a vital role to play in guiding global progress. The practical policy implications for funding, regulating and investing in research and innovation are profound.

> 'With a scope and detail unmatched in any other single framework, the goals are unprecedented in their span across social, economic and environmental issues.'

For centuries, 'progress' in STI has been viewed as whatever happens to emerge over time.[2] The tacit assumption is often that research and innovation governance is more about what *can* be done, rather than what *should* be done. Political leaders, for example, might assert that it is the rightful place of science to drive wider social progress, without addressing other drivers of progress or acknowledging that some outcomes of science might have negative impacts. And the commonly held view that one cannot stop scientific progress ignores the many ways in which prioritizing certain kinds of science or innovation inevitably accelerates particular types of progress and curbs others.

Strategies for investing in research and technology worldwide are routinely presented as 'pro-innovation', with little space for debating which particular kinds of innovations are being favoured and by which interests.[3] This narrow modernistic vision of progress ignores contending forms of science, alternative directions for research, and the choices between different innovation pathways.[4]

SDGs enable socially deliberate STI progress

The SDGs have set in motion the building of a shared global framework for holding research and innovation, and all kinds of change, to account. Instead of STI priorities being driven by the most privileged and powerful interests, the SDGs enable and require consideration of other priorities. Instead of research and innovation pathways being viewed as hard-wired, the SDGs encourage an opening up of political spaces, allowing critical questions and greater creativity in relation to how STI can help to achieve sustainability. Instead of rhetoric that these powerfully-backed paths are 'pro-innovation' (and that their critics are 'anti-science'), more nuanced attention can be paid to options, values and interests that may otherwise have remained sidelined.

How different influences shape STI

But what does this mean for scientific autonomy? Do the SDGs threaten to introduce stifling constraints on research and innovation? Any reasonable answer to this question must be no. For all the importance of the scientific values of independence, openness and scepticism, research and innovation have nonetheless always been subject to cultural, political and economic influences. Worldwide, many powerful interests and structures encourage particular directions for research and innovation and suppress others – too often reinforcing existing inequalities.

Overall, those areas of research that offer the greatest potential in terms of private profit, market control, national advantage or military domination tend to benefit from the largest funding streams and the most enthusiastic political and commercial support.[5] It is a reflection of this internal politics of science, for instance, that the largest single area for public STI funding around the world is military and security related.[6]

Political missions are typically focused around specific types of technology as a means to an end (for example, aerospace, nuclear, machine learning, nanotechnology, or gene editing) rather than on the ends in themselves (for example, goals relating to food, water, energy, shelter, mobility or communications).[7] The result has been a tendency to prioritize advanced technology over other kinds of innovation that might be more effective in achieving the SDGs. In food and agriculture, for example, molecular genetics tends to be disproportionately supported, compared with other scientific methods or social, political or behavioural approaches.[8]

Likewise, within science itself, there can be a tendency to prioritize research that focuses on the reductive categories (such as genes or functional molecules), over which intellectual property rights can most easily be exercised. This can lead to the side-lining of research that takes a more societal, relational or systemic approach. Although this type of research can be more difficult to appropriate, it can often be far more effective in addressing the SDGs.[9]

This focus on particular STI categories also means that negative impacts can be overlooked. For example, while there is much focus on the opportunities offered by digital technologies in relation to achieving the SDGs, less attention is given to the extent to which these technologies can drive inequalities by further concentrating data ownership and market power.[9]

It is crucial to recognize that all innovation is at least as much social as it is technological, and that many of the most promising technological innovations in relation to the SDGs are dependent on behavioural, organizational and political change.[10] There is very little that new technologies can achieve on their own.[11]

The role of the SDGs in steering STI

In short, the SDGs offer a means for researchers, funders, policymakers and societies at large to reflect, in fair and accountable ways, on which directions for research or innovation are most likely to count as progress in relation to the SDGs.

However, the most appropriate direction for research or innovation in any given context is typically far from self-evident. There is no sustainability goal or metric so precise that it is not possible for views to legitimately diverge. Thus, prioritizing the directions for STI in relation to the SDGs is an unavoidably qualitative and political challenge.

This does not mean, however, that anything goes. Across all views, some possible directions for science and technology may be quite easily set aside in favour of alternative pathways. This may be especially so in relation to some of the influential drivers of research and innovation that are absent from the SDG framework, such as private profit, market share, national prestige or military dominance.

The role of the SDGs in helping to steer more sustainable STI is not about asserting any specific political agenda, but about defining a shared political space to oversee the current drivers and directions in STI. A full range of scientific disciplines and fields of engineering or wider social practice are free to make the case for why, and under what conditions, particular directions for innovation may offer the best route to sustainability in a particular setting. The important point is for these contending cases to be rigorously scrutinized, rather than simply imposed or assumed in favour of the most powerful interests. This report makes a small contribution towards this end.

Dimensions of complexity around STI and the SDGs

Multiple aspects of the SDGs

Of course, many uncertainties, complexities and obstacles lie in the path of these ambitions. The SDGs span multiple aspects of, and perspectives on, human well-being, social equity and ecological integrity. The 17 goals, 169 targets and 231 indicators are just the visible tip of an iceberg of deeper implications and entanglements between ostensibly discrete issues. Addressing any one of these issues inevitably affects others. The history of technology is replete with examples of powerfully-backed 'solutions' to one problem becoming causes of another, sometimes more serious, calamity.[11] The lessons for research and innovation are profound.

Variety of STI activities and actors

Another crucial factor is the wide scope and variety of STI activities. The category system used by the OECD yields 42 broad fields of STI research and development, each divided into multiple individual topics, disciplines and associated communities of interest.[12] The Institute for Scientific Information's classification scheme, as used in this report, divides science into 254 subject categories, each with its own priorities,

Figure 1.1 / Dimensions of complexity

SUSTAINABLE DEVELOPMENT GOALS

17 Goals | 169 Targets | 231 Indicators

DIVERSE INFLUENCES ON STI

Individuals and communities of researchers, all with their own aims and values.

Institutionalized disciplines, each with their own distinctive understandings and cultures.

Priorities for research and innovation are also shaped by governments and businesses, driven by specific interests and politics.

[close to]
200 NATION STATES
with a vast array of geographical, jurisdictional and cultural settings

An estimated **108 types of ecosystem**, each with its own implications for relations between society, technology and environments.

Variations in socio-ecological contexts can affect ability to address many SDGs.

Stark differences in power, privilege and capacity

e.g. national governments differ from each other **by a factor of more than 100,000** in the resources they can mobilize.

addressed through the contrasting lenses of more than 21,000 academic journals.[13] In the field of technological applications, the International Patent Classification divides technology into around 70,000 distinct areas.[14]

These contrasting fields of science and innovation are comparable in their multiplicity to the complexities of the problems they seek to solve. STI is practised by diverse individuals and communities of researchers, all with their own aims and values. It takes place in a range of institutionalized disciplines, each with their own distinctive understandings and cultures. And the priorities for research and innovation are strongly shaped by governments and businesses, driven by specific interests and politics.

Variations in socio-ecological contexts

Cutting across these complexities are enormous variabilities of context. With close to 200 nation states and even more officially-recognized nationalities in the world,[15] there exists a vast array of geographical, jurisdictional and cultural settings in which diverse forms of research and innovation seek to address a multiplicity of social and environmental challenges.

Beyond this, the world supports an estimated 108 types of ecosystem, each with its own implications for relations between society, technology and environment.[16] To take another important indicator of divergent context, there are now more than 500 cities in the world of more than one million inhabitants, each with its own distinctive history and constituting issues.

Across this bewildering vista, there are stark differences in power, privilege and capacity. The per capita income of the richest countries of the world, for instance, is well over 100 times that of the lowest income countries. National governments differ from each other by a factor of more than 100,000 in the resources they can mobilize, with wealth concentrated massively at the top of this distribution. Production in some sectors is similarly concentrated in a few firms with the highest shares of capital and mark-ups, especially in industries with rapid rates of innovation.

Such inequalities exert crucial influences on the ability to address many SDGs. For instance, countries may differ by a factor of 42 in their neonatal mortality rate; of 10 in the share of population with access to electricity; of 50 in the share of population with access to the internet; of 2,500 in the number of scientific and technical journal articles per 1,000 population; and more than 1,000 in per capita energy related CO_2 emissions. Fairness and equality in and around STI are crucial to achieving sustainability.

Diverse perspectives

One key aspect in achieving greater fairness and equality lies in acknowledging the inherently political (not just technical) dimensions around both sustainability challenges and STI directions. Each one of the multiple permutations of SDG issues, STI possibilities and socio-ecological contexts can be viewed from a plurality of contrasting political perspectives, built on different values, interests and understandings.

It is clear that the number of contending STI 'directions' and 'pathways' to achieve the SDGs extends across many orders of magnitude. Assumptions that only one STI pathway offers a self-evident, sound science or pro-innovation way forward in any given context are clearly mistaken or misleading. Questions are always to be asked over why any research or innovation pathway should be supported more than another, which interests to prioritize, whose values count, and how to hold influential interests to account.

Addressing the challenges of aligning STI with SDGs

Amid such complexities, it is clear that there can be no one-to-one mapping of STI solutions onto problems. There is no shortage of particular interests asserting the sustainability benefits of their own favoured directions for research or innovation. Nor is there any shortage worldwide of mission-oriented agencies addressing specific aspects of the SDGs in terms of their own remits, for instance by asserting claims about what particular technologies can do for sustainability, rather than asking in more balanced ways, which STI directions would be best for specific SDG aims.[17]

What needs strengthening in the governance of science and technology around the globe are tools and resources to support open and inclusive processes of deliberation, focusing on alternative directions for STI in specific settings.[9] There is a need for careful quantification and rigorous analysis alongside attention to uncertainty and variability, so as to stimulate, inform and support a lively participatory worldwide debate.

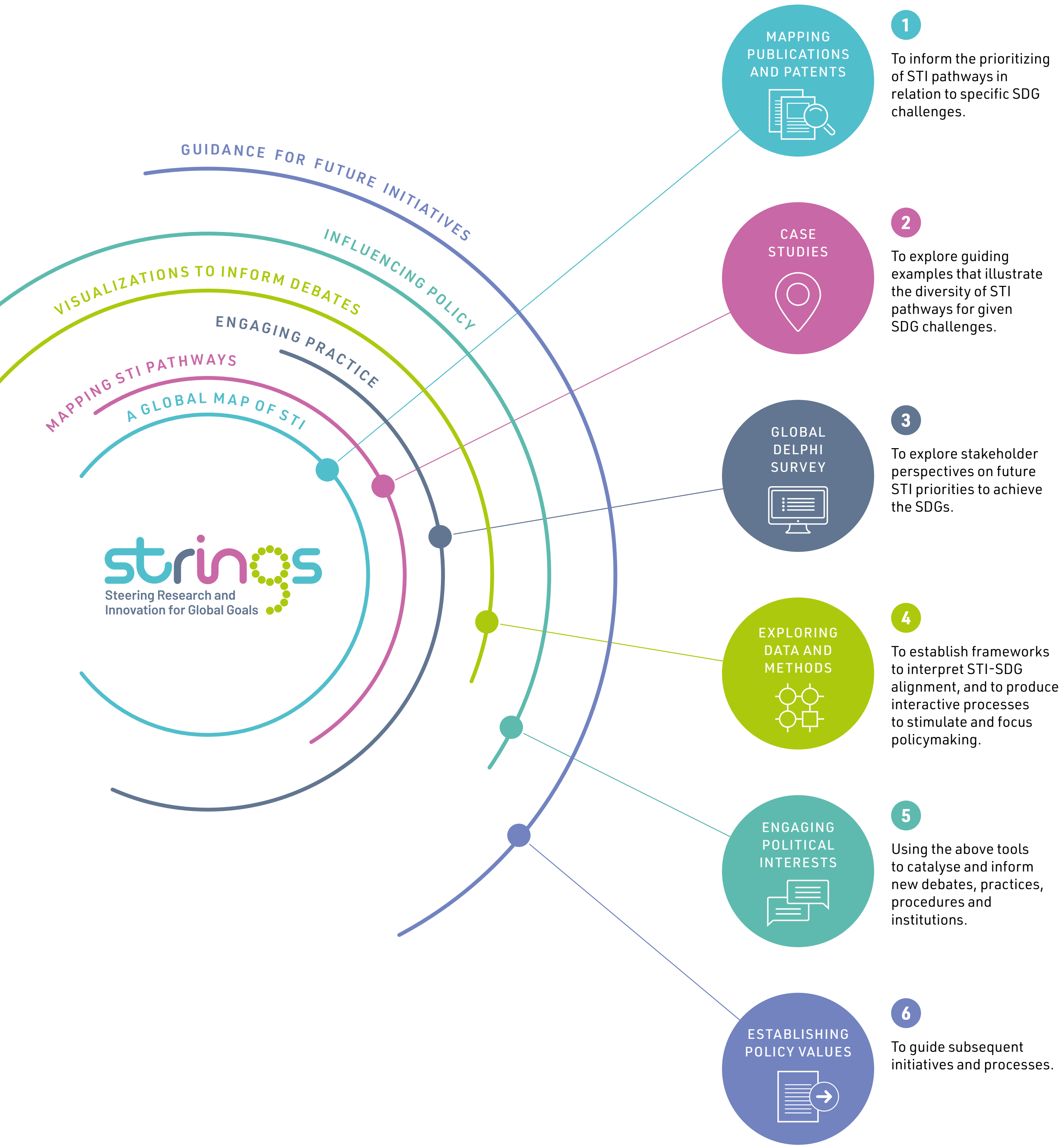
The core aim of this report is to address this need. Building on sporadic prior efforts, we aim to provide new evidence and tools for global mappings, clearer visualizations and better understandings of the alignments between STI and the SDGs. In this way, we seek to open up, motivate and guide international governance attention to the challenge of aligning STI more effectively with the progressive social and environmental values embodied in the SDGs. See pages 34 and 35 for further explanation of the STRINGS project's goals.

Our aim is to enable the appropriate prioritization of the interests of different groups, including those currently unjustly marginalized in global research and innovation, for example, exploited workers, disappropriated landholders, disenfranchised constituencies, oppressed communities, neglected regions and excluded nations especially in the Global South.

Although the challenge of aligning STI with the SDGs is highly complex and intractable, these difficulties need not impede these progressive ambitions. Simply to ask questions about direction is itself a crucial first step. Even relatively incomplete and qualified evidence may prove highly valuable in highlighting the shortcomings of dominant STI pathways in particular settings.

Figure 1.2 / A summary of the goals of the STRINGS project: from concept to implementation

For more detailed information see page 35.



The goals of the STRINGS project

The STRINGS project aims to provide an empirically-based, globally-produced analysis to empower policy action. Our goals are as follows:

1

To produce mappings that inform the prioritizing of STI pathways in relation to specific SDG challenges. Given the pioneering nature of this analysis and its early stage, these initial findings can only be incomplete. They are 'heuristic' guides, rather than definitive prescriptions. The scope and depth of the complexities also lead to a degree of open-endedness. These limitations underscore, rather than diminish, the importance of robust policy appraisal processes. By producing quantitatively rich and qualitatively 'thick' data, this project encourages wider evidence-gathering practices to inform policy.

2

To explore guiding examples, based in particular geographical, environmental and political settings, to yield case studies that illustrate the diversity of STI pathways for given SDG challenges. These case studies also demonstrate how active governance of the alignment between STI and the SDGs can be undertaken using reproducible methods in a range of real-world circumstances.

3

To challenge and interrogate current directions and priorities of STI in particular settings. We do so by asking rigorously about possible future STI directions that might otherwise be neglected; about social and political perspectives on STI that may be currently marginalized; and about the practical value of fostering a greater diversity of STI pathways.

4

To explore data and methods to identify priorities, so as to:

- establish systematic frameworks for questioning directionality and alignment around STI and the SDGs
- pioneer new applications of established or adapted methods
- experiment with novel hybrid approaches (especially combining qualitative interpretive and quantitative analytic practices)
- produce interactive processes and associated visualizations to help stimulate and focus policymaking and wider political attention

5

To contribute to building formative governance networks.

Over the course of the project, we have reached out to earlier and parallel initiatives, involving a diversity of actors and movements that are broadly concerned with the same issues around aligning STI with the SDGs.

Centring around a new global 'platform observatory', our recommendations are to engage policy actors and wider political interests in addressing this central challenge. By using the above tools to catalyse and inform new debates, practices, procedures and institutions within and across government, business, academic and civil society, we aim to aid deliberation, negotiation and the commissioning of further analysis and institution-building.

6

To nurture and benchmark crucial policy values to guide initiatives and processes. These values include:

- **rigour** in addressing neglected challenges of directionality in STI, diversity in STI pathways and pluralities of perspectives
- **transparency** in the clear and comprehensive representation of associated issues, uncertainties and complexities
- **openness** in the inclusion of diverse perspectives, forms of expertise and, as much as possible, data
- **accountability** in the provision of robust justifications for the pursuit of particular STI responses to specific SDG challenges

The scope and complexities of this task mean that it will never be possible to encompass a full or definitive picture of the appropriate directions for research and innovation. Nonetheless, we hope to provide concrete data and practical tools for provoking and guiding the many kinds of onward progress that can meet the challenge of the SDGs.

Notes

1. Brundtland 1987; United Nations Conference on Environment and Development, 1992; United Nations, 2015.
2. Stirling, 2009.
3. Sveiby et al, 2012; Godin and Vinck, 2017; Wright et al, 2018.
4. Government Office for Science, 2014.
5. House of Lords, Volume 1, 2010.
6. OECD (a), 2021; House of Lords, Volume 2, 2010.
7. Kattel and Mazzucato, 2018.
8. House of Lords, Volume 1, 2010.
9. Ely et al, 2010.
10. Nicholls et al, 2014.
11. Tenner, 1999.
12. OECD (b), 2021.
13. https://clarivate.libguides.com/webofscienceplatform/coverage
14. https://worldwide.espacenet.com/patent/help/ipc
15. United Nations, 2021.
16. Keith et al, 2020.
17. Miller, 2007.

> CHAPTER 2

A review of existing literature

Academic and policy discussions on STI-SDG relations

AUTHORS

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Footnotes for this chapter are on page 39. A full list of references can be found on page 140.

OVERVIEW

- This chapter examines current academic and policy literature about the relationship between STI and the SDGs. After developing a search methodology, we identified recent publications and summarised their discussions into four broad, related themes:

  Synergies and trade-offs between SDGs

  Misalignment between STI and the SDGs

  Approaches to shaping STI towards the SDGs

  Monitoring of the success of STI for the SDGs

- We found that many publications proposed approaches to shaping STI investments and policies towards the SDGs. Yet less effort has been made in trying to understand what works and how to evaluate the efficacy of different approaches.

- By studying what has already been achieved, and identifying potential gaps and limitations in the literature, this chapter informs our own approaches and methods.

Introduction

Science, technology and innovation (STI) policies have a crucial role to play not only as a way to boost R&D, productivity and the competitiveness of nations, but also to solve some of the major issues highlighted in the SDG targets, such as reducing poverty and inequalities, and improving life on land or water. In order to better understand this role, we set out to analyse the main findings from recent academic and policy publications (both scientific papers and grey literature) that examine the relationships between STI investments/policies and the SDGs.

After developing a search methodology (see Appendix 1 for more details), we identified 58 recent publications. The findings and discussions in these publications were then grouped in four different themes:

1. Synergies and trade-offs between SDGs
2. Misalignment between STI and the SDGs
3. Approaches to steering STI towards the SDGs
4. Monitoring the success of STI for the SDGs

We created these themes based on our interpretation of the major topics addressed by all the identified publications. The aim of this chapter is not to produce a comprehensive literature review, but to provide some context about current bodies of research that can then inform how we can steer STI towards achieving the SDGs.

Synergies and trade-offs between SDGs

The first theme relates to the synergies and trade-offs between SDGs – that is, whether improvements in some SDG areas are linked to improvements (or negative consequences) in other areas. It is crucial to understand these complex relations between the SDGs before exploring the other themes.

Several publications argue that studying the interaction between SDGs is essential for the efficient design of public policies (including STI), since an integrated approach can save resources and reduce costs by exploiting the positive links, or **synergies**, between SDG targets and minimizing the negative ones, or **trade-offs.**[1]

The literature in this category has applied various methodologies to study the links between SDGs, although most analysis assesses these interactions at the level of individual SDG targets. On the empirical side, many authors have used a time series of SDG indicators to correlate co-evolution between them.[2] Other approaches have relied on expert opinion, theoretical models, or a review of the literature to identify essential interlinkages between SDG targets.[3] Additionally, text mining approaches have been used successfully to assess synergies and trade-offs.[4] For instance, Le Blanc (2015) finds that, of 107 SDG targets, 60 explicitly refer to at least one goal other than the one to which they belong. This aspect of the SDGs is frequently mentioned as an improvement on the Millennium Development Goals, which formed a less integrated system.[5]

Figure 2.1 / Key themes in the literature

Overall, the literature agrees that positive interactions between SDG targets outweigh the negative ones.[6] There is also consensus that the relationships between different SDG targets are greatly context-dependent, varying according to geographical location, governance context, number and types of people affected, and the time frame.[7] For example, increasing fishing activity in a certain region can lead to a reduction of hunger (↑ SDG target 2.1 and 2.3) and improved livelihoods in the short-term (↑ SDG target 8.5). With time, however, fish stocks may become overused, with the same effort leading to less and less yield, unless sustainable management practices are put in place (↓ SDG target 14.4). The context-dependencies make it difficult to draw generalizable conclusions about interactions that may ultimately depend on locally specific factors.[8]

Misalignment between STI priorities and the SDGs

Publications in the second group consider the reasons for the potential misalignments between STI priorities and the SDGs, that is, why STI investments do not always help to meet the SDGs. One issue highlighted is the **uneven distribution of STI activities across countries**. Most STI activities take place in high-income countries, which means they tend to focus on themes and problems that are less relevant to the problems of the worldwide majority.[9] For example, it is argued that the concentration of technology in the hands of a few companies in high-income countries has often oriented economic growth in consumption-led directions, which are not typically in the interests of the SDGs.[10]

> 'Most STI activities take place in high-income countries, which means they tend to focus on themes and problems that are less relevant to the problems of the worldwide majority.'

Another factor mentioned in the literature is that, within most countries, **societal priorities differ substantially according to economic status**. For example, a survey sent to 34 African countries[11] found that hunger (SDG 2), health (SDG 3), water and sanitation (SDG 6), access to energy (SDG 7), and infrastructure (SDG 9) were the issues that mattered most to the poor. In contrast, the wealthiest respondents were more likely to cite jobs and economic growth (SDG 8) and peace, justice and strong institutions (SDG 16) as priorities. Since decisions about STI priorities emerge from complex interactions between policymakers, funders, researchers and innovators, each with their own incentives and institutionalized practices, it is possible that in many cases STI prioritization is not well aligned with the needs of the poorest residents.

Another important finding is that **some forms of STI contribute to environmental degradation, disrupt livelihoods and exacerbate inequalities**.[12] It has been argued, for example,[13] that at least nine SDGs could be negatively impacted by advances in automation and artificial intelligence, primarily through the direct and indirect consequence of increased unemployment but also through threats in emergent sectors like the 'gig' and 'on-demand' economies.

Approaches to steering STI towards the SDGs

Literature associated with the third theme identifies various approaches that can be taken to shaping STI to meet the SDGs. These include:

i) A focus on **directionality** of STI policies towards the SDGs – in other words, ensuring that national development and STI efforts are aligned with the country's commitment towards the 2030 Sustainable Development Agenda. Such efforts can take the form of challenge- or mission-oriented approaches, or other incentives for directing STI activities towards the SDGs. In most cases, these approaches include the demand side and involve stakeholders in policy design and implementation.[14]
ii) **Plans, roadmaps or integrated assessments** of STI investments and policy, which are developed and agreed jointly by public, private and civil society actors.[15] These plans might involve, for example, identifying technology gaps or creating research and development roadmaps.
iii) **Promoting inclusive and grass-roots innovation policies** that consider the specific situations and needs of poor people, women and vulnerable groups to achieve more equitable, sustainable and inclusive development.[16]
iv) **Strengthening national systems of innovation in developing countries** (for example, improving infrastructure, lowering barriers to technology use and diffusion, building STI literacy and capabilities) and **fostering well-functioning institutions** (for example, strengthening political stability, educating workforces, and strengthening the science-policy interface) **in order to boost economic, environmental, social and cultural resilience** that will contribute to the achievement of the SDGs.[17]
v) **Using the SDGs as an opportunity for developing countries to 'leapfrog' to sustainable frontier technologies.**[18] For example, some people in developing countries who have previously had no access to electricity are bypassing fossil fuels by adopting solar electricity, thus leaping directly to the stage of renewables. By doing so, they are not only contributing to SDG 7 (Affordable and clean energy), but also developing capabilities and skills in a set of technologies that will be critical in the future.
vi) Considering the broad **transformations/transitions**[19] that are required in the wider economy to achieve the SDGs by 2030. One study,[20] for example, focuses on six

key transformations required to achieve the SDGs by 2030: (1) education, gender and inequality; (2) health, well-being and demography; (3) energy decarbonization and sustainable industry; (4) sustainable food, land, water and oceans; (5) sustainable cities and communities; and (6) digital revolution for sustainable development. Central to these transformations are technology-intensive transitions and the need for open and effective governance at all levels.

Monitoring the success of STI for the SDGs

While the literature contains several theoretical approaches, less has been published about understanding what works and how to evaluate the success of STI in achieving the SDGs. The inherent complexity of all 17 SDGs and the variety of pathways by which different areas of STI can contribute to specific targets make it difficult to rigorously evaluate impact and specific relations.[21] Yet, the existence of indicators associated with the SDG targets and the requirement for the collection of standardized data provide an important opportunity to monitor the relationships between STI and the SDGs.[22]

An important issue relating to SDG indicators is that many national statistical systems have faced severe challenges in tracking progress, which requires an unprecedented amount of data and statistics at all levels.[23] The Global SDG Indicators Database[24] reveals that, for four of the 17 goals, less than half of the 194 countries or areas have produced internationally comparable data. Even some countries with available data have recorded only a small number of observations over time, making it difficult for policymakers to monitor progress and identify trends.

Therefore, most literature related to this theme recommends increased investments in national data and statistical systems and the mobilization of additional international and domestic resources to guarantee the internal consistency, comparability and overall quality of data produced to advance the 2030 Agenda. This is especially relevant in lower-income contexts, where, arguably, these actions and investments should be complemented by an operational/technical assistance budget dedicated to monitoring and evaluating policy.[25] In such countries, the literature argues, it is essential to enhance capacities related to monitoring and accountability in order to establish policies that help to achieve the SDGs.

On a positive note, some of the literature argues that advances in technology and the proliferation of data are providing new opportunities for monitoring and tracking the progress of the SDGs. A promising avenue is the data produced through **citizen science**, which can complement and ultimately improve the SDG reporting process.[26] Fritz et al. (2019) provide concrete examples of how citizen data are currently being adopted as well as highlighting potential areas for future contributions. For example, volunteers in the Philippines are collecting household census data on poverty, nutrition, health, education, housing and disaster risk reduction, which are then used by the Philippine Statistics Authority to enhance their statistics on 32 SDG indicators.

Conclusion

Overall, our review found several proposed approaches to help steer STI investments towards the SDGs. Partially due to the complexity of the issues at hand, less effort has been made in trying to understand what policies and investments work, and how to evaluate their efficacy. Understanding the mechanisms that foster STI to help achieve the 2030 Agenda in specific contexts, and how to measure performance and progress, are significant research gaps. The STRINGS project aims to address these gaps – both by developing methodologies that track misalignments between STI and the SDGs at the global level and by analysing how well different STI pathways are aligned to specific SDG challenges in our case studies in East Africa, India and Argentina.

Notes

1. Alcamo et al., 2018; Allen et al., 2018; Barbier and Burgess, 2017; Donoghue and Khan, 2019; Elder et al., 2016; ICG, 2017; Kumar et al., 2018; Scharlemann et al., 2016.
2. Fonseca et al., 2020; Pradhan et al., 2017; Sebestyén et al., 2019.
3. Fuso Nerini et al., 2018; McCollum et al., 2018; Moyer and Bohl, 2019; Nilsson et al., 2018, 2016.
4. Le Blanc, 2015; Dörgő et al., 2018.
5. Fukuda-Parr, 2016.
6. Barbier and Burgess, 2019; McCollum et al., 2018; Nilsson et al., 2018; Pradhan et al., 2017.
7. Breuer et al., 2019; Nilsson et al., 2018; Scharlemann et al., 2016.
8. McCollum et al., 2018.
9. United Nations, 2019, 2014; Walsh et al., 2020.
10. Walsh et al., 2020.
11. Coulibaly et al., 2018.
12. UNCTAD, 2017.
13. UNDP, 2018.
14. Giovannini et al., 2015; Mazzucato, 2018; UNCTAD, 2018, 2017.
15. Allen et al., 2019; IAP Workgroup, 2019; IATT, 2018, 2020; Miedzinski et al., 2019; United Nations, 2016a; United Nations Economic and Social Council, 2015.
16. UNCTAD, 2017; United Nations, 2016b.
17. IAP, 2019; Leal Filho et al., 2018; United Nations, 2016b, 2016c, 2014.
18. United Nations, 2018.
19. Sachs et al., 2019a; Schot and Steinmueller, 2018; The World in 2050, 2018.
20. Sachs et al., 2019.
21. Adenle et al., 2020; Cervantes and Hong, 2018; United Nations, 2016a.
22. Gusmão Caiado et al., 2018; Reyers et al., 2017; Salvia et al., 2019.
23. ISSC, 2015.
24. United Nations, 2020.
25. IAP Workgroup, 2019; Namubiru-Mwaura and Marincola, 2018; Schmalzbauer et al., 2016.
26. Fritz et al., 2019; Quinlivan et al., 2019.

SECTION 2
THE RESEARCH

> CHAPTER 3

An overview of the research design

Combining analytical angles, methods and disciplines to investigate STI-SDG relations

AUTHORS

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Ine Steenmans

Footnotes for this chapter are on page 47. A full list of references can be found on page 140.

OVERVIEW

The plurality, diversity, and complexity of science, technology and innovation (STI) and of the SDGs require study of diverse actors with diverse methods from different disciplines. Combining methods enables us to look at the STI system from different angles and analytical perspectives.

This chapter explains the STRINGS project's research design:

- We study **four groups of actors** involved in the production and use of STI.
- We bring together **three analytical angles:** past STI priorities in the global research system, current local STI pathways, and views on future STI priorities from multiple perspectives.
- We combine **three main methods:** data analysis to map global STI; three local case studies; and a global Delphi survey.

The different angles of analysis can be compared, combined, and juxtaposed to provide a rich picture of complex STI-SDG relations.

Introduction

The complexity of the relations between science, technology and innovation (STI) and the Sustainable Development Goals (SDGs), as outlined in Chapter 1, means there is no simple nor unique way to map STI to the goals. A common feature of previous attempts to understand the contribution of STI to the SDGs (see Chapter 2) is a focus on a single method or a single angle of analysis (for example, the synergies and trade-offs between SDGs, grassroots innovations, or public STI funding mechanisms). This report looks at the issue more broadly – combining disciplines and methods, and considering STI-SDG relations from multiple research angles to inform various uses in policy and practice.

> 'By combining methods from a range of disciplines, we provide complementary mappings, characterizations and understandings of the complex relations between STI and the SDGs.'

In a compromise between cutting through the STI-SDG complexities and embracing them, we make use of multiple analytical tools to examine STI-SDG relations for different types of actors, across geographical settings and time horizons. By combining methods from a range of disciplines, we provide complementary mappings, characterizations and understandings of the complex relations between STI and the SDGs. We are then able to build on these mappings and characterizations to illustrate and explain misalignments between STI activities and the SDGs. In Section 3, we propose several ways to steer STI towards the SDGs.

The current chapter outlines the research design of the analytical chapters in Section 2 of the report. It explains the three angles of analysis, each using different methods and focusing on different actors, and how the different angles and methods can be combined.

STI priorities are shaped by multiple actors

For simplicity, we group the actors that contribute to prioritizing, producing and using different forms of STI in four heterogenous and overlapping groups:

- Users, beneficiaries and consumers
- Civil society organizations, advocacy groups and practitioners
- Policymakers, funders, aid agencies and philanthropies
- Public and private research organizations

Figure 3.1 is a stylized interpretation of the multiple relationships between these different groups of actors and their influence on and use of STI.

Users, beneficiaries and consumers are individuals and groups – such as farmers, patients or mothers – who have a range of needs and face various different challenges related to the SDGs, for example, hunger, poverty, climate change and conflict. They address these challenges by producing and using knowledge and innovations. Only a fraction of the challenges faced by users goes on to influence the direction of STI in public and private organizations. The extent of the influence depends on how the challenges are understood, mediated and prioritized by civil society organizations, policymakers, funders and aid agencies. Users may also influence research organizations directly, including those in the private sector (for example, through 'bottom of the pyramid' innovations that aim to sell goods and services to the untapped market of the poorest people).[1]

Civil society organizations, advocacy groups and practitioners act as an interface between users and the other actors. Based on their own political and STI priorities, values, perspectives and interests, they prioritize some of the SDG-related challenges faced by users, and go on to influence policymakers and research organizations.

In turn, **policymakers, funders, aid agencies and philanthropies**, also with their own priorities, values, interests and perspectives, select some of the issues presented by civil society organizations and users, for instance by translating them into certain SDG targets. Based also on these targets, policymakers, funders, aid agencies and philanthropic organizations define research funding priorities and the research and industrial policies that influence public and private research organizations.

Finally, **public and private research organizations** produce much of the scientific research, technologies and market-oriented innovations that could address users' challenges, and help achieve the SDGs. Researchers in these organizations have their own priorities, values and perspectives, and make a further selection of which challenges to address and how.

As a result of these varied interactions, only a small portion of the challenges faced by users are addressed in the

STI system, and they may be tackled according to priorities and values that differ from those of users. Moreover, only a limited selection of the technologies, knowledge and innovations produced by research organizations ultimately reaches policymakers, civil society and users – for example, through new technologies, practices and policy recommendations.

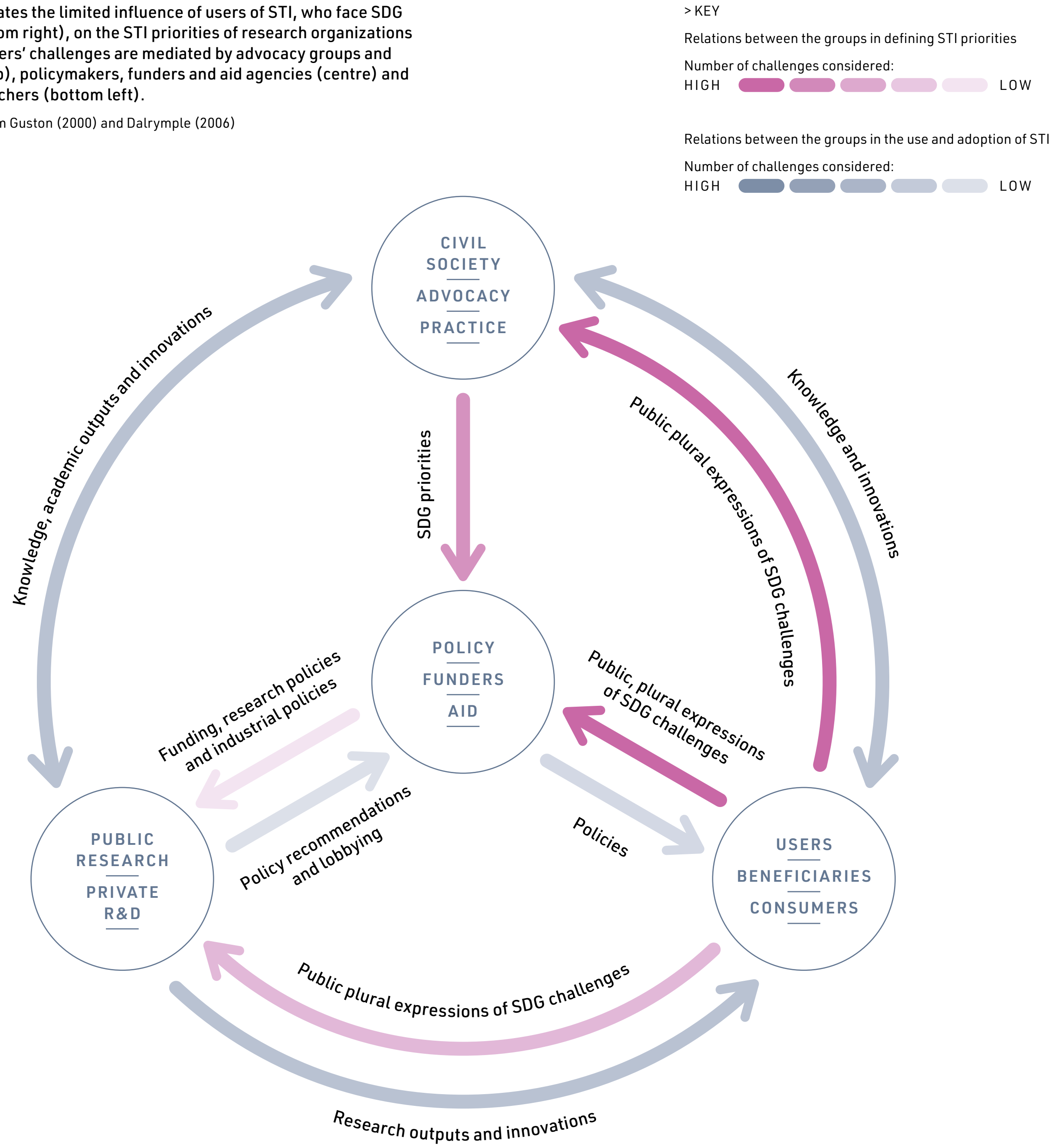
Of course, not all STI is produced in research organizations. Civil society organizations, policymakers and users also produce knowledge and innovate in relation to the SDGs – for example, by adapting existing technologies and pursuing social, policy and grassroots innovations.

The relationships between the four groups of actors are complex, non-linear, and vary across different dimensions of time and space. In the analysis throughout the report we map some of these relationships and analyse how they may influence the alignment between the SDGs and STI.

Figure 3.1 / Setting STI priorities: interactions between actors

The figure illustrates the limited influence of users of STI, who face SDG challenges (bottom right), on the STI priorities of research organizations (bottom left). Users' challenges are mediated by advocacy groups and practitioners (top), policymakers, funders and aid agencies (centre) and individual researchers (bottom left).

Source: Adapted from Guston (2000) and Dalrymple (2006)



STRINGS analytical design and methods

This report uses three angles of analysis to map and characterize STI priorities and to investigate their alignment with SDG-related challenges. The three angles encompass different actors (see Figure 3.1), time dimensions (past priorities, future beliefs and current struggles for STI directions) and geographical dimensions (from local to global).

Each angle is explored through a set of methods and focuses on one or more of the actors, one time dimension, and one geographical dimension.

Figures 3.2 and 3.3 summarize how these methods, actors and dimensions combine in the analysis in forthcoming chapters, and which specific research questions they address.

Figure 3.2 / Overview of the research design: research questions, angles of analysis, actors and methods

	CHAPTER TITLE AND QUESTIONS ADDRESSED	ACTORS	METHODS
ANGLE 1: **PAST** STI PRIORITIES IN THE **GLOBAL** RESEARCH SYSTEM (PAST, GLOBAL)	**4 A global map of science** **5 A global map of technological inventions** • What SDG-related STI has been carried out where, in what discipline and by which public and private research organizations? • What are the interactions across SDG-related areas of research and inventions? • How does SDG-related STI differ from other types of STI? **6 STI-SDG alignment across countries** • To what extent have research organizations in different countries prioritized research that relates to their own countries' main SDG challenges?	**Public and private research organizations**	**Data analysis; scientometric analysis; text mining; network analysis; statistical analysis**
ANGLE 2: BELIEFS ABOUT **FUTURE** STI PRIORITIES ACROSS DIFFERENT **CONTEXTS** AND ACTORS (FUTURE, CONTEXTS)	**7 Future STI priorities** • What types of STI should be prioritized to achieve the SDGs by 2030? • What are the synergies and trade-offs between those STI types? • Is there a consensus about future directions of STI? • How far are future priorities aligned with the current priorities in private and public organizations?	**Civil society organizations, practitioners, policymakers and research organizations**	**Global real-time Delphi survey**
ANGLE 3: **CURRENT** DIVERSE **LOCAL** STI PATHWAYS (CURRENT, LOCAL)	**8 Alternative STI pathways** • How are STI pathways constituted in practice by different actors? • How do the different groups of actors, with their different priorities, interests and values, shape local STI priorities and pathways to address SDG-related problems? **9 Misalignments between STI pathways and SDGs** • How do conflicting prioritizations lead to misalignments between STI pathways and SDG challenges?	**Users, civil society organizations, policymakers and research organizations**	**Local case studies based on document review, interviews, workshops, questionnaires and focus groups** **Multicriteria mapping**

Angle 1

Analysis of past STI priorities in the global research system

Using scientometric techniques we analysed published academic research and patented inventions across the world. These STI documents provide information about research and innovation priorities, which are the result of the complex interactions between actors (see Figure 3.1).

Using network analysis and text mining, we developed a mapping of these documents in relation to the SDGs. This enabled us to study past SDG-related STI prioritizations across countries, organizations, disciplines and SDGs.

We also studied which research areas and technology fields may be best placed to understand synergies and tensions between SDGs, and the extent to which SDG challenges have been considered in isolation, or as interrelated problems that need multiple understandings of STI.

As a result, we proposed a typology of SDG-related research, which can help to improve future prioritization of STI to better address the SDGs (Chapter 4).

Using the data on past STI prioritizations, we then analysed the extent to which countries have changed their research specializations in the past in response to SDG challenges (Chapter 6). This enabled us to consider the alignment between countries' research priorities and their greatest SDG challenges.

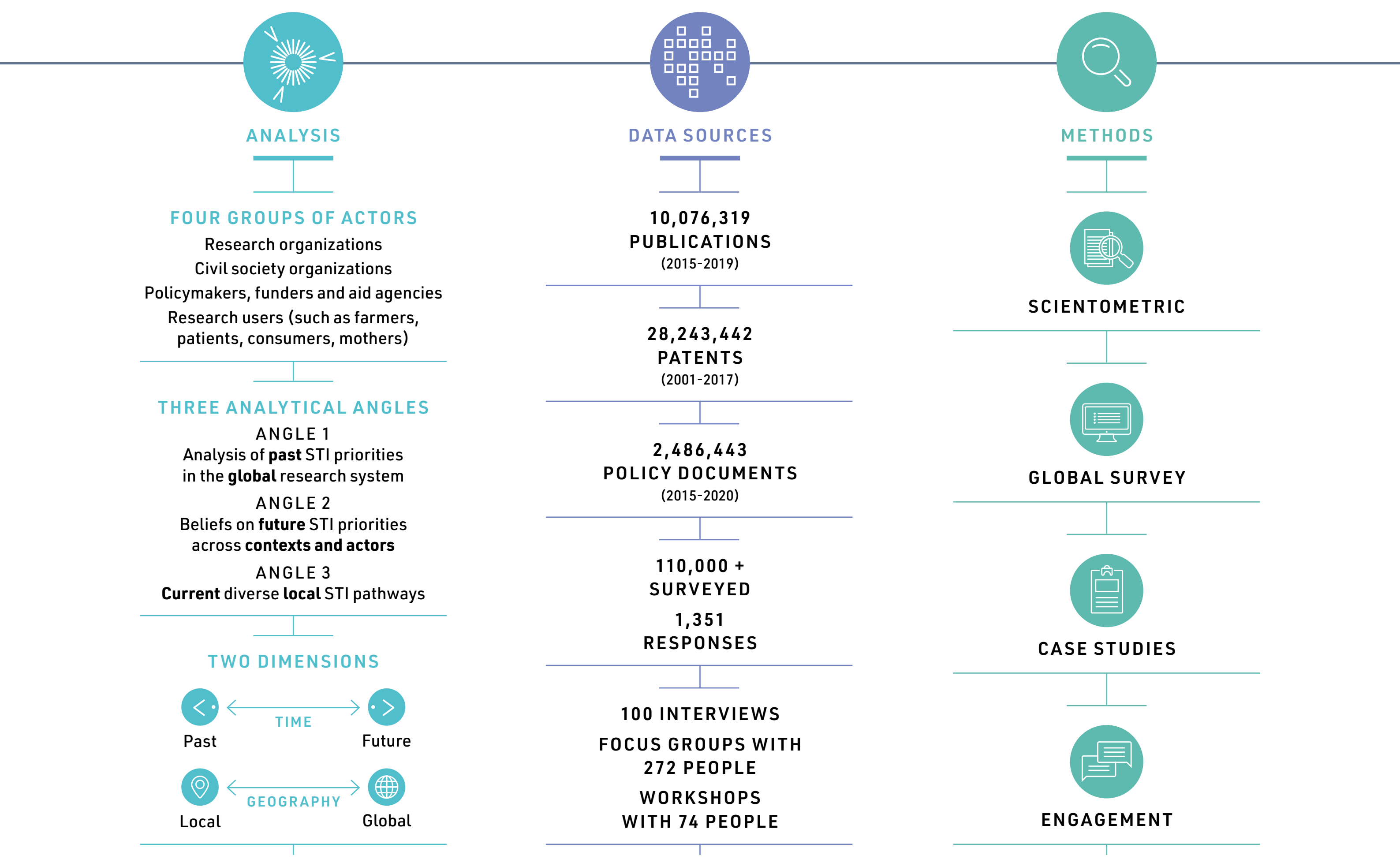
Angle 2

Beliefs about future STI priorities across contexts and actors

We ran a global, real-time Delphi survey, which was sent to more than 100,000 individuals from public and private research organizations, civil society organizations and policymaking bodies, in a range of regional contexts across the world (Chapter 7). Respondents shared their opinions about what STI is most likely to influence the achievement of the SDGs, either positively or negatively, by 2030.

The responses allowed us to better understand the wide range of STI types and priorities, beyond academic and market-oriented inventions, and which of these are more or less

Figure 3.3 / The STRINGS project: a multi-method, multidisciplinary study



controversial across SDGs, contexts and groups of actors. They also provided a deeper understanding of synergies and trade-offs between different forms of STI over different SDG targets.

By contrasting respondents' priorities with the past STI prioritizations of public and private research organizations, we were able to explore alignments and misalignments between incumbent and desired STI.

Angle 3:

Current diverse local STI pathways

Finally, we explored three local case studies, each focusing on a particular SDG-related challenge: reducing the negative impacts of the Chagas disease in Argentina; increasing access to improved rice seed varieties resistant to climate change related stresses in Odisha, India; and tackling conflicts around overfishing in Lake Victoria, Kenya. Using documents, interviews, surveys and focus groups, we studied how different actors, each with their own priorities, understandings, values and interests, have contributed to shaping local STI pathways (Chapter 8). We then used multicriteria mapping to appraise different actors' views on how far each pathway aligns with sustainable development objectives (Chapter 9).

Combining evidence from the three angles

Beyond their separate contributions to mapping STI prioritization and pathways and analysing STI-SDG alignments, the three angles can be combined (Figure 3.4). We combine evidence from the three angles to investigate the relations between the different groups of actors (Figure 3.1) and between the different temporal and geographical dimensions (Figure 3.2 and 3.3).

For example, while the global map of STI in public and private research organizations (Chapter 4) provides an overall description of STI directions, it inevitably lacks context. We supplement this with an analysis of how local STI pathways (Chapters 8 and 9) are influenced by global and regional STI priorities in research. The local case studies illustrate the different ways in which STI pathways and priorities emerge and evolve. These insights help us to interpret the STI directions observed in the global mapping, and to understand how STI can be steered to improve alignment with the SDGs.

The mapping of STI priorities (Chapter 7) highlights the need to improve attention to diverse local contexts, which may not be well understood by global producers of STI.

We also combine our analysis of past STI activities with an analysis of current pathways and beliefs about future STI directions. For instance, in Chapter 7 we compare views about which STI should be prioritized in future with the STI directions that have attracted significant research and innovation in the recent past.

Finally, we consider how past global priorities may have influenced current local pathways, and whether these priorities have helped to support pathways that are aligned with the SDG challenges (Chapters 8 and 9).

Engaging with stakeholders

Throughout the project, we engaged with a wide range of stakeholders, including policymakers, funders, researchers, private sector organizations and international NGOs, both as primary data sources for our analysis and as users of our outputs.

Engagement, which ran through each of the three angles of analysis, involved:

- **Discussing** different STI prioritizations and directions and how they align with SDGs, with local and global users and funders
- **Engaging** the users of our outputs and seeking their feedback on design, format and content to ensure relevance and maximize utility
- **Disseminating** outputs and tools to explore the mappings, pathways and explanations identified in our work
- **Supporting and empowering** actors to orient STI for the SDGs through our outputs and events

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A two-day consultative workshop at the beginning of the project helped to fine-tune the research design and to identify key audiences and engagement strategies. This led to the following activities:

- Mapping and prioritizing users of our outputs to facilitate engagement and policy uptake
- Consulting our advisory committee to help formulate research and engagement activities that can maximize the project's impact
- Gathering feedback from different groups of actors on the first drafts of all chapters
- Ongoing communication, for example, through blogs, webinars, social media and newsletters, to raise awareness of and drive engagement with our work
- Delivering an empirically-based, globally-produced analysis that can empower policy action in the form of this report, accompanying materials and tools to explore the mappings, pathways and explanations identified in the project

Figure 3.4 / Combining analysis to understand STI priorities and their alignment with SDGs

Analysis	Analysis of past STI priorities in the global research system	Beliefs about future STI priorities across contexts and actors	Current diverse local STI pathways	Engagement with stakeholders
Analysis of past STI priorities in the global research system	Explore what SDG-related STI directions have been prioritized by public and private organizations in the past, across countries. Analyse how these priorities align with countries' main SDG challenges.			
Beliefs about future STI priorities across contexts and actors	Compare past STI priorities in research organizations (mainly in high-income countries) with opinions on future STI priorities across contexts and actors .	Explore diverse actors' beliefs, across different contexts, about STI priorities to achieve the SDGs by 2030.		
Current diverse local STI pathways	Analyse how local pathways may be Influenced by incumbent global STI.	Understand the perspectives of actors in different contexts and how their priorities may influence local STI pathways. Compare current local STI pathways with beliefs on future priorities.	Assess the influence of diverse groups of actors on local STI pathways and their perceptions of how the pathways align with sustainable development challenges.	
Engagement with stakeholders	Help local, regional and global funders and policymakers to understand STI prioritization and STI-SDG misalignments, and to rethink their priorities and planned actions.	Open up the discussion about future priorities, learning from plural actors and contexts. Support the inclusion and identification of different priorities.	Demonstrate to influential STI decision makers the importance of understanding and supporting different STI pathways. Encourage future prioritization by highlighting misalignments of current pathways.	Use research findings to help different actors in different contexts to steer STI towards the SDGs. Connect global and local policymakers and users.

The figure illustrates the various ways in which the different analytical angles (pale blue) and comparisons between them (dark blue) contribute to our understanding of STI priorities, how they differ in different geographical and time dimensions, how they are generated, and their alignment with the SDGs.

Notes

1. Prahalad and Hart, 2002.

> CHAPTER 4

A global map of science

Mapping and characterizing SDG-related research across the world

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Hugo Confraria
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Footnotes for this chapter are on page 61. A full list of references can be found on page 140.

OVERVIEW

This chapter uses publication data to map and characterize SDG-related research across the globe.

Key challenges include:

- Higher income countries dominate the research agenda yet publish the lowest proportion of research related to the SDGs
- Few opportunities exist for knowledge transfer and capacity-building in low-income countries
- There is less focus on complex underlying societal issues than on immediate technological solutions

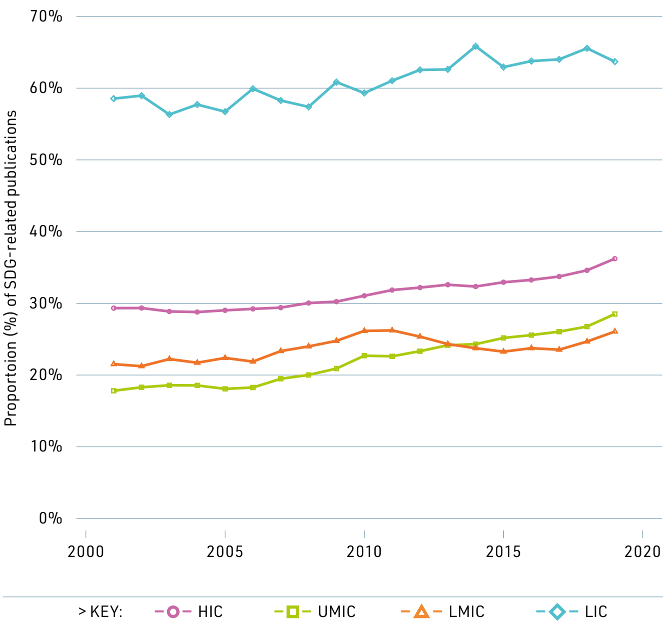
We also identified the following areas of opportunity:

- Research in low-income countries is strongly related to SDGs
- Some synergies exist between research on different SDGs
- SDG-related research, especially on society-related SDGs, is more multidisciplinary and more likely to be used in policy and reported in the media than other types of research

Introduction

This chapter presents our findings about the countries, organizations and research disciplines that carry out research related to the Sustainable Development Goals (SDGs). We also identify the research areas that produce research related to more than one SDG and are thus in a good position to understand synergies and trade-offs between different SDGs. Finally, we describe a typology of SDG-related research and examine how it differs from other types of research. The next chapter (5) maps innovation activity in a similar way, using patent data.

Figure 4.1 / SDG-related publications in different country income groups (2001-2019)



The graph shows the proportion of publications that relate to any of the SDGs (1-16). It is based on the total number of publications in countries in each of the four World Bank income groups (2021 definition): high-income countries (HIC); upper-middle-income countries (UMIC); lower-middle-income countries (LMIC); low-income countries (LIC). Based on strict interpretation of SDG-related research (see page 52 for definition). See Appendix 2, Figure A.2.1 for a figure based on the loose interpretation. Figures based on Web of Science data. Centre for Science and Technology Studies (CWTS) version.

Our research builds on several earlier scientometric studies, which have analysed who conducts certain types of research and how research is used and funded. For example, studies have examined the alignment of research with health challenges,[1] different actors' priorities in shaping research directions,[2] the funding practices of interdisciplinary research,[3] and the use of interdisciplinary research in policy.[4]

Recent years have also seen several efforts to link academic publications to specific SDGs. These include studies by academics; research councils; publication data providers such as the Web of Science and Dimensions; publishers such as Elsevier; United Nations agencies; and consultancies to regional and national governments.[5] Despite important differences in which academic publications are linked to SDGs, these studies usually find that most SDG-related research is carried out in high-income countries (HICs), that it focuses on just a few SDGs (mainly relating to health, climate and energy), and is concentrated in a few disciplines, although this focus differs between countries. Some of these studies also report that much SDG-related research focuses on more than one of the SDGs.

Our method, and how it differs from earlier studies, is explained on page 52.

A map of SDG-related research: SDGs, countries and disciplines

The proportion of publications that relate to any of the SDGs grew between 2001 and 2019, particularly after the launch of the Millennium Development Goals in 2005 and the introduction of the 2030 agenda in 2015. Yet the proportion remains low, particularly in higher income countries. As shown in Figure 4.1, 64% of publications from low income countries (LICs) relate to the SDGs, compared with just 34% in high-income countries (HICs), 26% in upper middle-income countries (UMICs), and 24% in low middle-income countries (LMICs). However, research by LICs has a limited contribution to global SDG-related research as it accounted for just 0.2% of all publications in the WoS between 2015-2019.[6]

Which SDGs attract most research?

Figure 4.2 shows, for each country group, the proportion of SDG-related research that focuses on each individual SDG. Of all the SDGs, SDG 3 (Good health and well-being) attracted the most research. Overall, 22% of WoS research was related to SDG 3, with just 30% related to the other 15 SDGs covered in this study combined. Environment-related SDGs – SDG 13 (Climate action), SDG 14 (Life below water) and SDG 15 (Life on land) – also attract a large share of research in all countries. Most of the remaining SDG-related research in LICs relates to SDG 1 (No poverty), SDG 2 (Zero hunger) and SDG 5 (Gender equality), while the remaining research in LMICs and UMICs is mostly linked to SDG 7 (Affordable and clean energy) and

SDG 6 (Clean water and sanitation). The other SDGs attract relatively little research, especially those related to conflict and inequalities (5, 10, and 16), education, decent work and economic growth and innovation (4, 8, and 9) and sustainable behaviour (11 and 12).

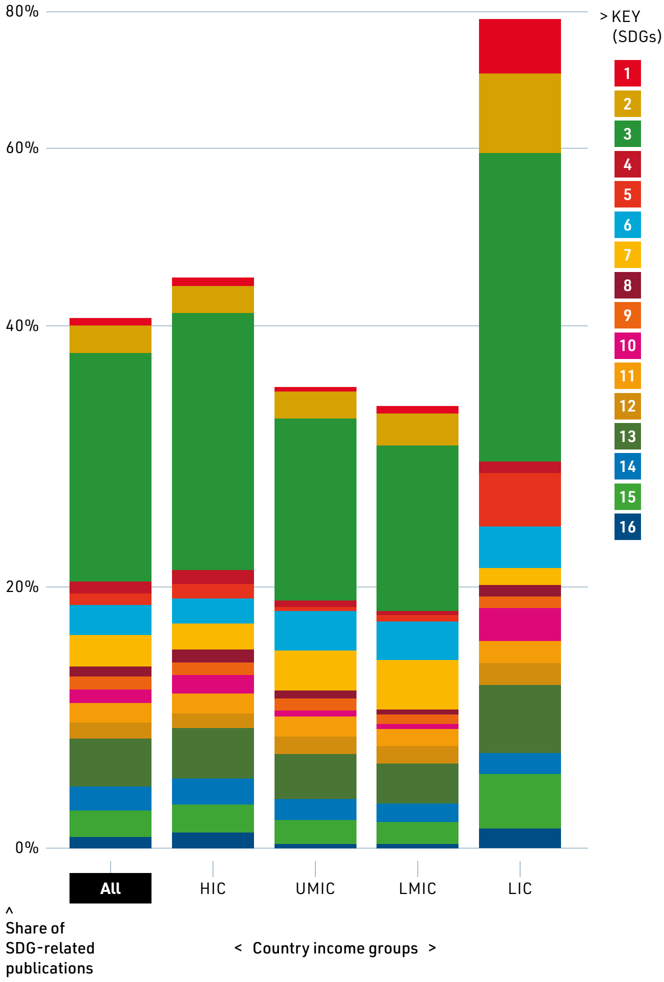
For some SDGs that attract a low share of research, publications have grown rapidly since 2001, as shown in Figure 4.3. For example, publications relating to SDG 11, 12, 9 and 8 have been among the fastest growing in most country groups. On the other hand, those related to pressing inequalities, conflict and education (SDGs 4, 5, 10 and 16) have grown less rapidly, with the exception of SDG 16 (Peace, justice and strong institutions) in LICs and SDG 4 (Quality education) in LMICs and UMICs. The greatest increase has been in publications relating to SDG 7 (Affordable and clean energy).

> 'The other SDGs attract relatively little research, especially those related to conflict and inequalities (5, 10, and 16), education, decent work and economic growth and innovation (4, 8, and 9) and sustainable behaviour (11 and 12).'

In HICs and UMICs, the growth of SDG-related publications has mostly plateaued since 2015, following 10 years of high growth. The exceptions are publications related to SDG 1 (No poverty) in HICs and to environment-related SDGs (13,14 and 15) and SDG 6 (Clean water and sanitation) in UMICs, which have continued to grow. In LMICs and LICs, publications have continued to grow for most SDGs, except for SDG 4 (Quality education) and SDG 7 (Affordable and clean energy) in LMICs.

Despite growing at different rates, the relative importance of the different SDGs in published research has remained remarkably stable across all country groups for 15 years, in line with the proportions shown in Figure 4.2.[7]

Figure 4.2 / Share of publications related to the SDGs by country group (2015-19)



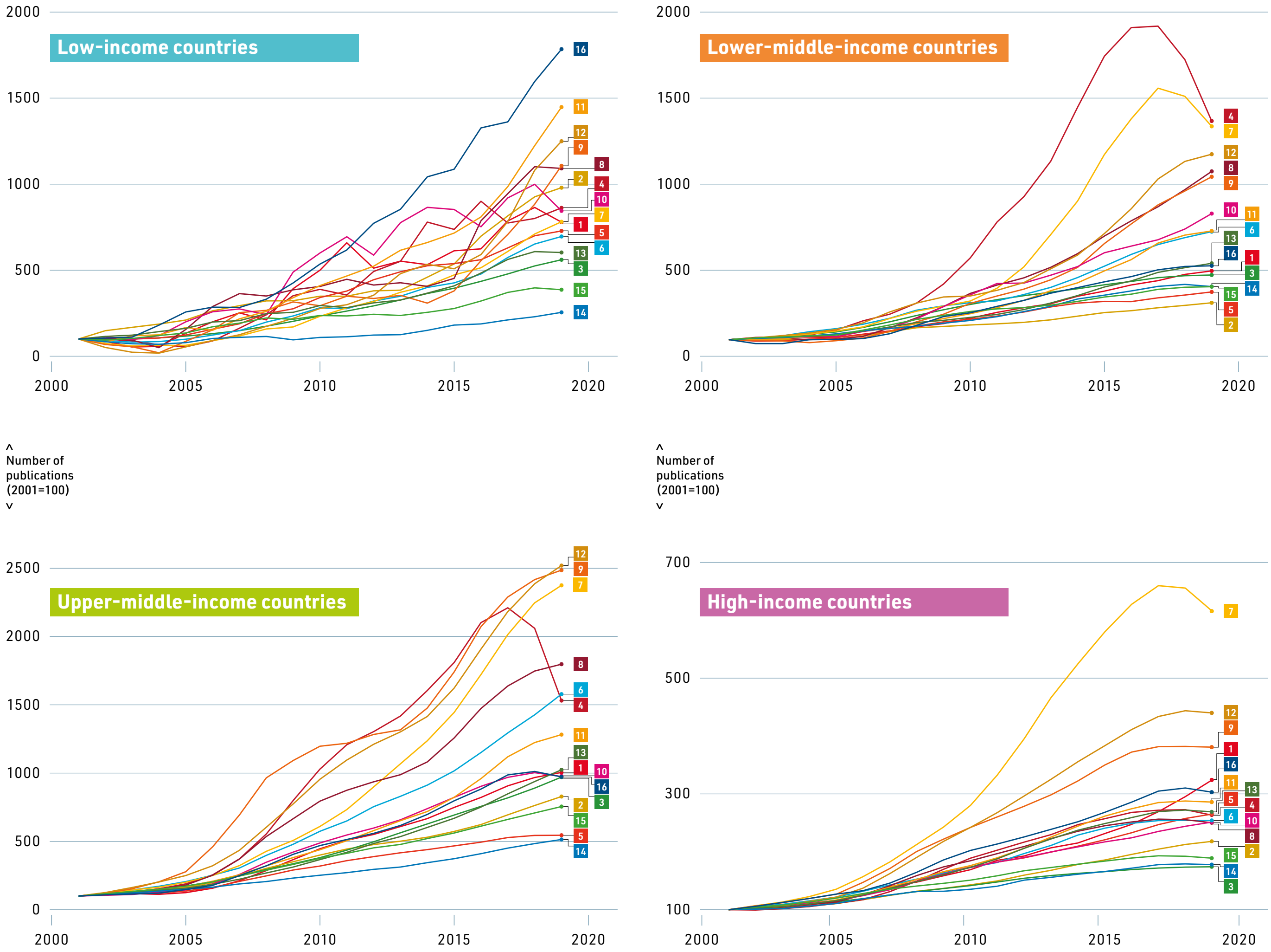
The chart shows the proportion of SDG-related research that relates to each SDG. Data is shown for each group of countries, defined according to World Bank classifications (2021 definition): high-income countries (HIC); upper-middle-income countries (UMIC); lower-middle-income countries (LMIC); and low-income countries (LIC). The proportions of SDG-related research shown here are higher than those in Figure 4.1, as Figure 4.2 uses the loose interpretation of SDG-related research (see page 52 for definition) in order to better show the differences in focus between country groups. See Appendix 2, Figure A.2.2 for a figure based on the strict interpretation.

Figures based on Web of Science data; Centre for Science and Technology Studies (CWTS version).

> KEY: **Sustainable Development Goals**

- **SDG 1** No poverty
- **SDG 2** Zero hunger
- **SDG 3** Good health and well-being
- **SDG 4** Quality education
- **SDG 5** Gender equality
- **SDG 6** Clean water and sanitation
- **SDG 7** Affordable and clean energy
- **SDG 8** Decent work and economic growth
- **SDG 9** Industry, innovation and infrastructure
- **SDG 10** Reducing inequality
- **SDG 11** Sustainable cities and communities
- **SDG 12** Responsible consumption and production
- **SDG 13** Climate action
- **SDG 14** Life below water
- **SDG 15** Life on land
- **SDG 16** Peace, justice, and strong institutions
- **SDG 17** Partnerships for the Goals

Figure 4.3 / Growth of SDG-related publications (2001-19)



The graphs show the publications index for each SDG and for each World Bank income country group (2021 definition). The number of publications in 2001 is set to 100. Numbers for other years show the percentage growth in the index since 2001 (for example, 1000 would indicate ten times as many publications as in 2001). Based on the strict interpretation of SDG-related research (see page 52 for definition). See Appendix 2, Figure A.2.3 for figures based on the loose interpretation.

Figures based on Web of Science data (CWTS version).

> KEY: **Sustainable Development Goals**

- **SDG 1** No poverty
- **SDG 2** Zero hunger
- **SDG 3** Good health and well-being
- **SDG 4** Quality education
- **SDG 5** Gender equality
- **SDG 6** Clean water and sanitation
- **SDG 7** Affordable and clean energy
- **SDG 8** Decent work and economic growth
- **SDG 9** Industry, innovation and infrastructure
- **SDG 10** Reducing inequality
- **SDG 11** Sustainable cities and communities
- **SDG 12** Responsible consumption and production
- **SDG 13** Climate action
- **SDG 14** Life below water
- **SDG 15** Life on land
- **SDG 16** Peace, justice, and strong institutions
- **SDG 17** Partnerships for the Goals

Mapping SDG-related research: our methods

To map and characterize what SDG-related academic publishing has taken place across the globe, we devised a method to assign research areas (groups of scientific publications related by citations) to specific SDGs. This approach reduces the uncertainty and ambiguity of assigning individual publications to an SDG,[8] and allows us to include publications that contribute to SDG-related research even if they do not use SDG-specific language in the title or abstract.

First, we **built a query** with a set of terms that are strongly associated with each SDG (from 1 to 16).[9] To capture a broad understanding of SDGs, we consulted policy reports, grey literature, scientific publications and web forums, alongside United Nations sources. We extracted relevant fragments from these texts, then selected keywords within them, first using text-mining techniques and then a manual selection.

We then used those SDG-related queries to **search 4,013 clusters of publications in the Web of Science** published between 2015 and 2019. A cluster comprises a number of published documents which are related to each other because of their citation pattern.[10] Each cluster, then, represents a **research area** covering broadly similar topics.

Based on the results of the search, we connected each research area to one or more SDGs, depending on the proportion of publications that included our SDG query terms in their title and abstracts. For example, 22% of publications in the 'multidimensional poverty' research area[11] used terms relating to **SDG 1** (No poverty).

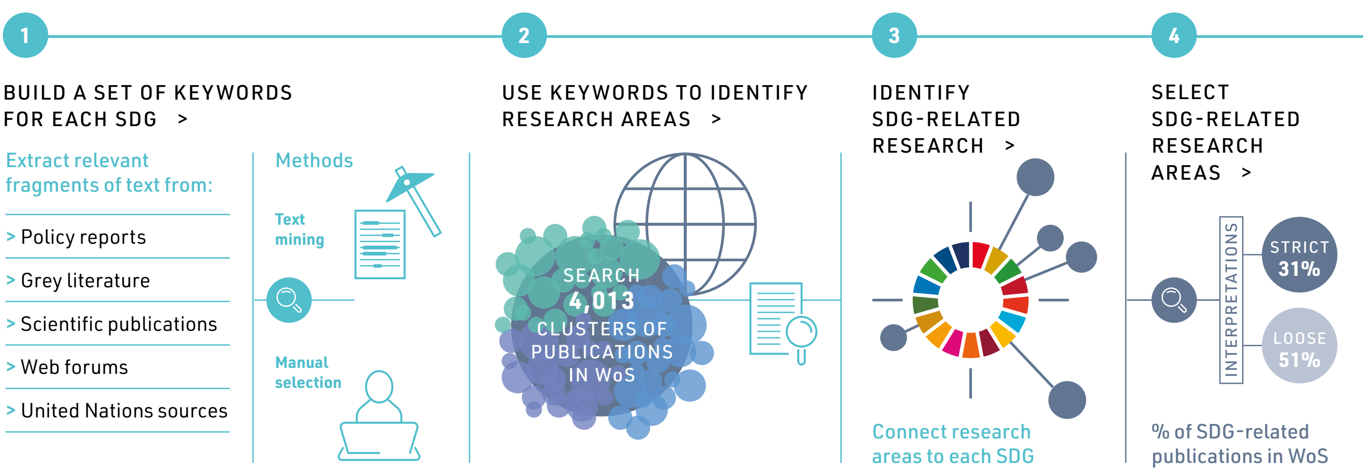
The results in this chapter are based on two different interpretations of SDG-related research, as follows:

- The *strict* interpretation includes only those research areas with publications directly related to the SDGs. Under this interpretation, 31% of all WoS research between 2015 and 2019 was SDG-related (1,120 research areas out of 4,013).
- The *loose* interpretation also includes research areas with publications that are less directly related but which may still be relevant. Under this interpretation, 51% of all WoS research between 2015 and 2019 was SDG-related (1,911 research areas).

As with all studies that map research published in academic journals, these methods are subject to certain limitations. In particular, the WoS does not cover most non-English language journals or those that focus mainly on topics of local relevance.[12] Moreover, much research, especially in low-income contexts, is not published in academic journals. However, our findings are still crucial in mapping and characterizing the contribution to the SDGs of academic research, which accounts for a large proportion of research funding and is widely used in policy and society. In Chapter 12, we suggest a tool and method that allows users to review the results in this chapter using different interpretations of SDG-related research.

More detail about the methods, which are fully replicable, is provided in Appendix 2.

Figure 4.4 / An overview of our approach



Countries' capabilities for SDG-related research

In order to address local sustainability challenges, it is important for countries to build their own research and innovation capabilities. However, the vast majority (92%) of all publications in the WoS between 2015-19 were published by researchers in HICs and UMICs. This figure rises to 94% if we consider only SDG-related publications.[6]

Within income groups, the distribution of research is also extremely skewed, as shown in Figure 4.5. China accounts for 58% of all UMIC publications, India 57% of LMIC publications, and Ethiopia and Uganda 49% of LIC publications.[13]

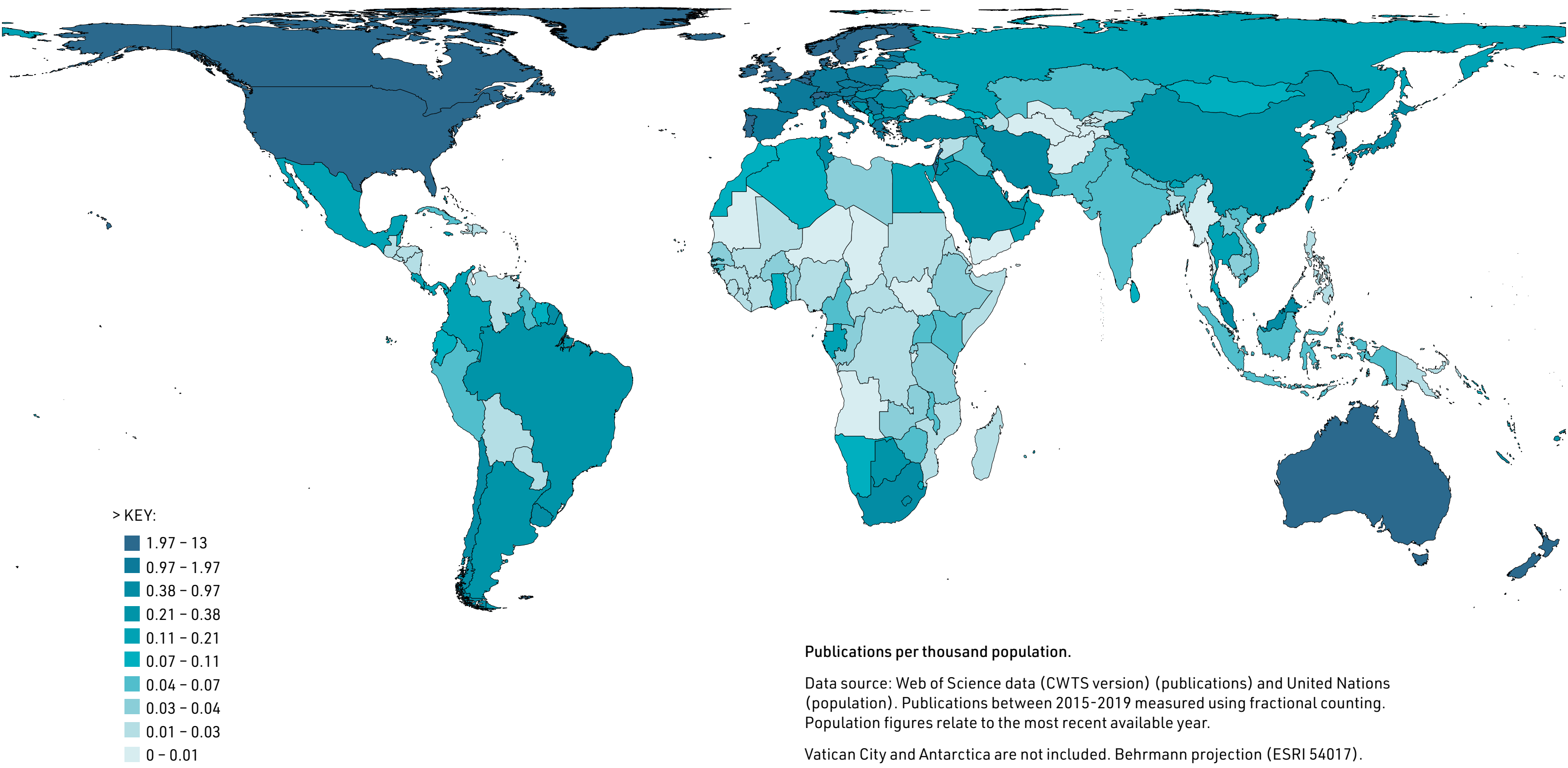
SDG-related research is also highly concentrated in just a few organizations. 50% of SDG-related publications in the WoS are produced by between just 1.9% (for SDGs 4 and 16) and 3.6% (for SDGs 8 and 9) of the 8,000 research organizations in our data.[14]

Those countries that are poorly represented in SDG-related research (LMICs and LICs) are similarly underrepresented in SDG-related research collaborations with the HICs and UMICs that dominate the SDG research agenda, as shown in Tables 4.1 and 4.2. Despite efforts by funding agencies to fund collaborative research with LMICs and LICs, 89% of all co-authored publications are between authors that work in HICs or UMICs.

Collaborations between authors in HICs and LMICs account for just 1.2%, and those between HICs and LICs just 0.2%, of global collaborations (Table 4.1). These represent just 2% of total collaborations for authors in HICs. Meanwhile, 38% of LIC collaborations and 22% of LMIC collaborations are with HICs (Table 4.2). South-South collaborations (between UMICs and LMICs or LICs) are marginal: respectively 0.3% and 0.04% of total collaborations, and 1.2% and 0.2% of all UMIC collaborations.[15]

Such imbalances mean that global and local research priorities and capabilities are directed by a few countries.[16] LICs, which have a relatively high domestic share of publications related to SDG 1 (No poverty) or SDG 2 (Zero hunger), for example, produce far fewer publications in these areas than HICs, which produce a significantly smaller domestic share of research on these topics, but which have high numbers of research organizations and researchers.[17] Similarly, countries at the frontier of military research[18] dominate research on SDG 16 (Peace, justice and strong institutions) although the domestic share of publications on this topic is substantially higher in several fragile LICs and LMICs,[19] which have a significantly smaller research capacity.[20]

Figure 4.5 / SDG-related publications per capita (2015-19)



Publications per thousand population.

Data source: Web of Science data (CWTS version) (publications) and United Nations (population). Publications between 2015-2019 measured using fractional counting. Population figures relate to the most recent available year.

Vatican City and Antarctica are not included. Behrmann projection (ESRI 54017).

Table 4.1 / Collaborative SDG-related publications within and between each country group (as a percentage of global collaborations)

COUNTRY GROUPS	HIC	UMIC	LMIC	LIC
HIC	66.32%			
UMIC	3.65%	18.69%		
LMIC	1.19%	0.28%	3.78%	
LIC	0.24%	0.04%	0.06%	0.30%
TOTAL	3,121,395 (71.40%)	990,797 (22.66%)	231,707 (5.30%)	27,607 (0.63%)

Table 4.2 / Collaborative SDG-related publications within and between each country group (as a percentage of a country group's total collaborations)

COUNTRY GROUPS	HIC	UMIC	LMIC	LIC
HIC	92.89%	5.12%	1.67%	0.33%
UMIC	16.12%	82.48%	1.23%	0.18%
LMIC	22.43%	5.25%	71.27%	1.04%
LIC	37.65%	6.31%	8.75%	47.29%

1a: This shows what proportion of all global collaborative publications occurred within (diagonal) and between (off the diagonal) country groups. For example, a publication co-authored by authors in the USA and the UK (both HICs) would contribute to the percentage in the top left cell. A publication co-authored by authors in the USA and Brazil (between HIC and UMIC) would contribute to the second row of the first column). The sum of all cells equals 100%.

1b: This shows what proportion of the collaborations within each country group occurred within and between country groups. For example, the first row shows the country groups involved in all collaborative research undertaken by HIC. The row total sums to 100%.

HIC: High-income countries; UMIC: Upper-middle-income countries; LMIC: Lower-middle-income countries; LIC: Low-income countries.

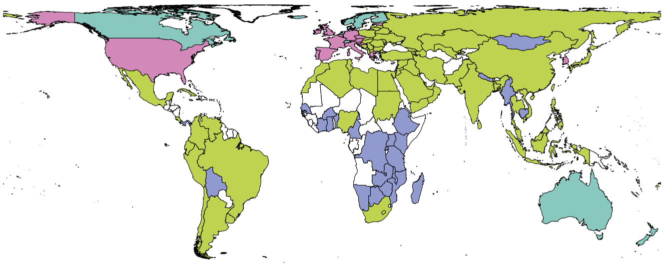
Figures are based on WoS data (CWTS version), 2015-19.

Which disciplines contribute to SDG-related research?

The involvement of different disciplines varies substantially across SDGs,[21] and not all disciplines publish on SDG-related issues. Because of the predominance of health-related publications in our sample, the 10 academic disciplines with the highest share of SDG-related publications are almost exclusively linked to health – for example, oncology, tropical medicine and parasitology. The 10 disciplines with the lowest share of SDG-related publications include basic sciences such as astronomy, astrophysics, physics and quantum science, and some of the humanities, including classics, medieval studies and literature.[22]

To investigate which disciplines may be relevant to more than one SDG, we calculated the median share of SDG-related publications for each discipline.[23] The 20 disciplines that relate to more than one SDG are predominantly in the social sciences, while most of the bottom 20 are disciplines related to health.

Overall, we found that the disciplines that publish on issues relating to one SDG are also likely to publish on issues relating to other SDGs (see Table 4.3 on page 57). For example, the disciplines that publish a high proportion of publications related to SDG 1 also produce a high share of publications related to SDGs 2, 5, 8, 9, 10, 11, 12 and 16. This indicates that funding research in a particular discipline may help to address several, related SDGs.

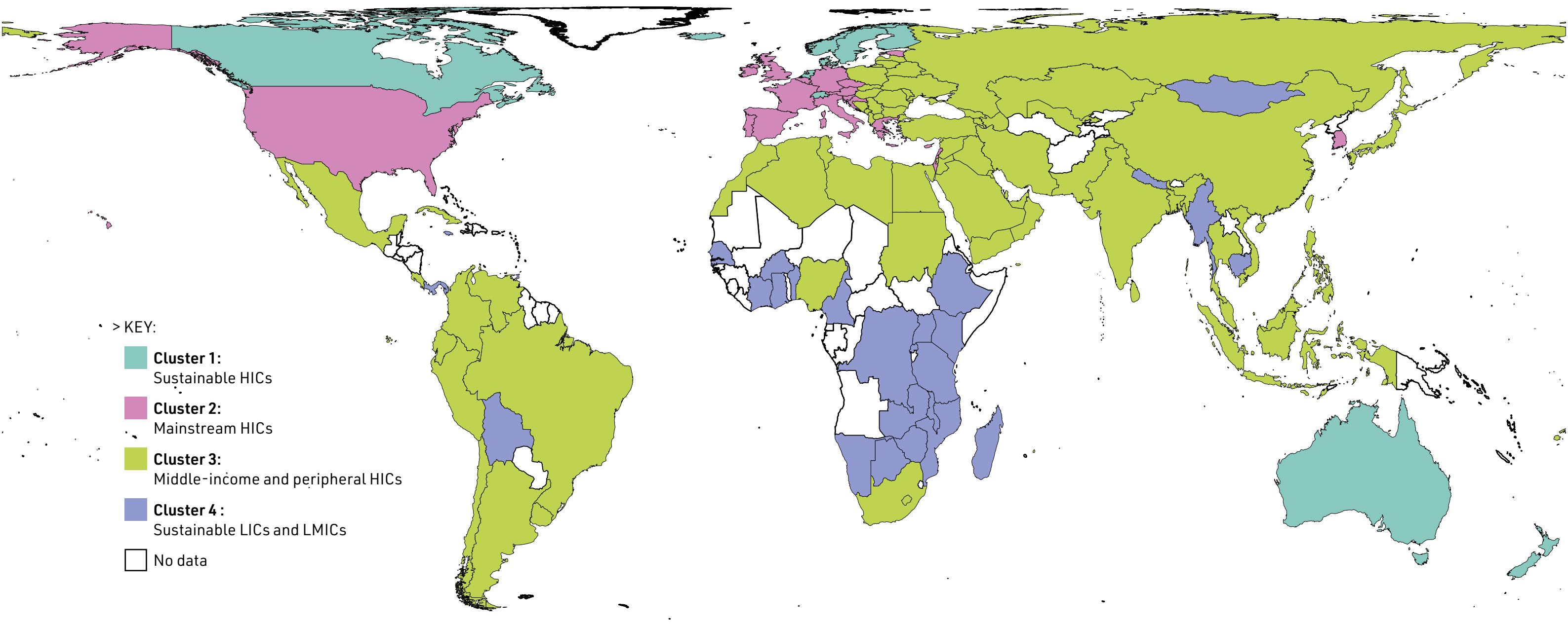


Country clusters

To distinguish different patterns of SDG-related research capabilities, we have identified four country clusters, as shown in Figure 4.6 on page 55.

These are based on common patterns of SDG-related publications, non-SDG-related publications, and overall research capacity (SDG-related publications per capita).[24] This produces a grouping that, while comparable to the World Bank income groups, better distinguishes countries by their capability to address the SDGs.

Figure 4.6 / Country clusters based on publications and research capacity



Cluster 1

SUSTAINABLE HICs

This group comprises the most research-intensive HICs.

Publications per capita:	3.6
2021 SDG Index ranking*:	80.2
Proportion of SDG-related publications	38%

They have an ***above average*** share of publications related to:

- **SDG 4** (Quality education)
- **SDG 9** (Industry, innovation and infrastructure)
- **SDG 10** (Reduced inequalities)
- **SDG 12** (Responsible consumption and production)
- **SDG 13** (Climate action)
- **SDG 14** (Life below water)

Cluster 2

MAINSTREAM HICs

Countries in this group, with the exception of Lebanon, are all HICs.

Publications per capita:	1.79
2021 SDG Index ranking*:	78.6
Proportion of SDG-related publications	32%

They have an ***above average*** share of publications related to:

- **SDG 4** (Quality education)
- **SDG 8** (Decent work and economic growth)
- **SDG 9** (Industry, innovation and infrastructure)
- **SDG 10** (Reduced inequalities)

They have a ***well below average*** share of publications on the environmental SDGs.

Cluster 3

MIDDLE-INCOME AND PERIPHERAL HICs

This is the largest group, combining those UMICs (47%) and HICs (26%)[25] with a below average number of publications per capita, alongside those LMICs (22%) with a low number of publications per capita.

Publications per capita:	0.3
2021 SDG Index ranking*:	70
Proportion of SDG-related publications	29.5%

Most countries in this group have a ***high*** share of publications related to:

- **SDG 6** (Clean water and sanitation)
- **SDG 7** (Affordable and clean energy)

UMICs and HICs in this cluster also have a ***high*** share of publications related to:

- **SDG 8** (Decent work and economic growth)
- **SDG 9** (Industry, innovation and infrastructure)
- **SDG 12** (Responsible consumption and production)

Cluster 4

SUSTAINABLE LICs and LMICs

This group is composed mainly of LMICs (52%) and LICs (30%).

Publications per capita:	0.06
2021 SDG Index ranking*:	58.7
Proportion of SDG-related publications	LMICs 55%; LICs 73%

They have a ***high*** share, particularly in LICs, of publications related to:

- **SDG 1** (No poverty)
- **SDG 2** (Zero hunger)
- **SDG 3** (Good health and well-being)
- **SDG 5** (Gender equality)
- **SDG 6** (Clean water and sanitation)
- **SDG 16** (Peace, justice and strong institutions)

They have an ***above average*** share, particularly in LMICs, of publications related to environmental SDGs.

*The SDG Index measures each country's progress towards achieving the SDGs

Notes on the map: Each colour identifies one cluster of similar countries. A strict interpretation of SDG-related research was used. Countries with less than 500 total SDG-related publications between 2015-19 were not counted because their share of publications per SDG is extremely volatile. Figures based on Web of Science data (CWTS version).

Whose good health and well-being? Research related to SDG 3

Our analysis shows that between 43% and 60% of SDG-related research published between 2015 and 2019 was related to SDG 3 (Good health and well-being). However, this research may make only a limited contribution to sustainable development.

To study the contribution of SDG 3-related publications, we connected them to the main disease on which they focus.[26] We found that most SDG 3-related research does not prioritize the diseases that most affect the health of the 36% of the world population living in low-income countries (LICs) and lower middle-income countries (LMICs), which also shoulder 45% of the global disease burden.

As shown in Figure 4.7, a large proportion of SDG3-related research in LICs and LMICs focuses on diseases that have a substantial impact in those countries, such as infectious and parasitic diseases. However, these countries produce just 6% of all global SDG-related research.

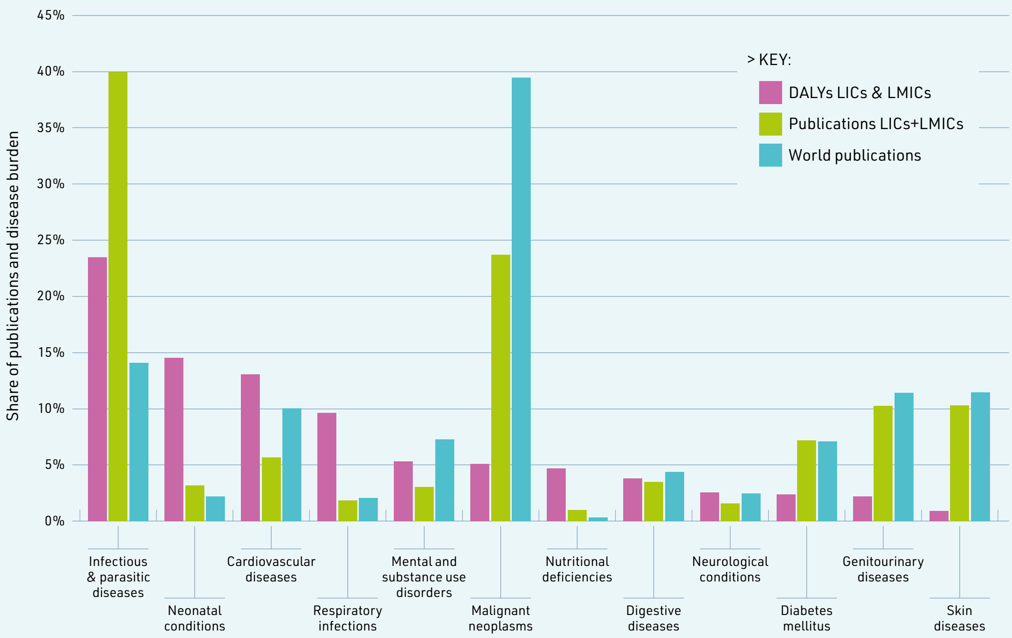
Worldwide, most SDG 3-related research does not prioritize the diseases with the largest impact on the lives of people in LICs and LMICs. Neonatal conditions, respiratory infections and nutritional deficiencies have a relatively high burden in LICs and LMICs, but research on these conditions is severely underrepresented both in these countries and globally.

Conversely, around 40% of global SDG 3-related research is focused on cancer (malignant neoplasms), which accounts for just 5% of the disease burden in LICs and LMICs. The major focus on this disease category in HICs and UMICs (where cancer represents 18% of the disease burden) also influences the focus of research in LMICs, where it accounts for 26% of total SDG 3-related research.

Likewise, diseases that represent 2% or less of the total disease burden in LICs and LMICs – diabetes, genitourinary diseases and skin diseases – account for a significant share of SDG 3-related research both globally and in LMICs.

Our findings indicate that even research that is related to a particular SDG will not always help to achieve SDG targets or meet the most pressing challenges. A substantial effort to include LIC researchers and stakeholders in research may go a long way to better align research funding with global health priorities, by directing funding towards diseases that affect the majority of the population.

Figure 4.7 / Disease burden in LICs and LMICs compared with share of related publications



Pink bars illustrate the burden of a particular disease category in LICs and LMICs, measured using disability-adjusted life years (DALYs), as a proportion of total DALYs across all disease categories in these countries. Only diseases with the highest burden are reported here. DALYs combine the number of years lost due to ill-health, disability or early death. Figures refer to 2010.

Green bars show LIC and LMIC publications that relate to each disease category, shown as a proportion of all LIC and LMIC publications related to SDG 3 that can be connected to particular diseases.

Blue bars represent global publications related to each disease category, shown as a proportion of all publications related to SDG 3 that can be connected to diseases.

Publication figures refer to 2015-19. Based on strict interpretation of SDG-related research. Figures based on WoS data (CWTS version) and on World Health Organization data (WHO, 2017).

Table 4.3 / How SDGs are related via different research disciplines

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00															
2	0.37***	1.00														
3	-0.01	-0.06	1.00													
4	0.04	-0.04	-0.05	1.00												
5	0.39***	-0.01	0.18**	0.10	1.00											
6	0	0.14*	-0.16**	-0.06	-0.10	1.00										
7	-0.01	0.08	-0.27***	-0.07	-0.14*	0.39***	1.00									
8	0.42***	0.14*	-0.16*	0.05	0.12*	0	0.06	1.00								
9	0.34***	0.18**	-0.19**	0.03	0.02	0.11	0.22***	0.56***	1.00							
10	0.44***	0.07	-0.03	0.17**	0.46***	-0.05	-0.06	0.62***	0.21***	1.00						
11	0.16**	0.13*	-0.16*	0	0	0.13*	0.16*	0.18**	0.34***	0.18**	1.00					
12	0.15*	0.25***	-0.20**	-0.01	-0.02	0.29***	0.44***	0.57***	0.42***	0.06	0.25***	1.00				
13	0.08	0.38***	-0.25***	-0.06	-0.10	0.40***	0.20**	0.07	0.17**	-0.01	0.30***	0.23***	1.00			
14	-0.05	-0.02	-0.14*	-0.05	-0.10	0.17**	0.01	-0.04	-0.03	-0.07	0	-0.02	0.33***	1.00		
15	-0.02	0.18**	-0.16**	-0.06	-0.10	0.16***	0.02	-0.02	0.01	-0.05	0.07	0.06	0.50***	0.50***	1.00	
16	0.14*	0	0.04	0.03	0.48***	-0.06	-0.07	0.09	0.04	0.16*	0.01	-0.02	-0.05	-0.02	-0.05	1.00

The table shows the pairwise correlation between the share of publications related to an SDG across all 254 disciplines (subject categories). Shares computed based on the strict interpretation of SDG-related publications. N=254; *p < 0.05, **p < 0.01, ***p < 0.001.

Figures based on Web of Science data (CWTS version).

Dark grey: A dark grey square indicates that several disciplines publish a similar share of publications related to this pair of SDGs.

White: A white square indicates that most disciplines produce different shares of publications related to this pair of SDGs.

Light grey: No statistically significant relationship in the share of publications of disciplines related to this pair of SDGs.

On the other hand, the fact that research related to some SDGs, such as SDG 4 (Quality education) and SDG 3 (Good health and well-being) is not correlated with research on other SDGs indicates that changes are needed in the research system. Education and health are related to many other sustainability challenges, and may therefore benefit from research in some of the disciplines that produce knowledge on these other challenges.

Also of concern is the fact that, while social sciences is the discipline that contributes to the widest range of SDGs, the SDGs that are most related to societal challenges do not benefit substantially from research in other disciplines.[27] We discuss these low synergies below.

Research synergies across the SDGs

In seeking to address complex sustainable development challenges, knowledge about interconnections between individual SDGs and targets can be as relevant as understanding how to address specific targets.[28] Because our method maps research to SDGs on the basis of research areas (clusters of publications) rather than individual papers, we can study in detail which research areas publish on several SDGs, and are therefore in a position to produce knowledge about the connections and synergies that could help in addressing the goals.[29]

Of the 1,120 research areas we identified as publishing SDG-related research (using our strict interpretation), 830 relate to just a single SDG,[30] while 43 relate to four or more different SDGs.[31] The SDGs that appear most in these synergistic research areas are those related to hunger (SDG 2), water and sanitation (SDG 6), and the environment (SDG 12, SDG 13 and SDG 15).

By analysing the 290 research areas that are related to more than one SDG,[32] we identified that SDG-related research tends to cluster around three areas. The clusters are detailed below. Figure 4.8 illustrates the links between and within these groups of SDGs.

SDGs in the green cluster are more strongly connected to each other than the SDGs in other clusters. Several research areas produce publications that are related to SDG 13, SDG 14 and SDG 15. These SDGs are also connected with SDGs in the yellow cluster, particularly through the connection between research related to SDG 13 (green) and SDGs 7, 12 and 6 (yellow).

Research related to the lilac cluster – people and society – is more isolated from other SDG-related research. The links between different SDGs within this cluster are also weaker than in the other two clusters, suggesting that few synergies are explored in research on these underlying society-related issues.

Within the yellow cluster, we found that research related to building science, technology and innovation (STI) capabilities, promoting inclusive and sustainable industrialization and fostering innovation (SDG 9) – which is the focus of this report

GREEN

A cluster of SDGs related to: the natural environment

SDG 13 Climate action
SDG 14 Life below water
SDG 15 Life on land

These are connected to the lilac cluster via:
SDG 2 Zero hunger

YELLOW

A cluster of SDGs related to: economic growth, infrastructures and technical solutions

SDG 6 Clean water and sanitation
SDG 7 Affordable and clean energy
SDG 8 Decent work and economic growth
SDG 9 Industry, innovation and infrastructure
SDG 12 Responsible consumption and production

LILAC

A cluster of SDGs mainly related to: people and society

SDG 1 No poverty
SDG 4 Quality education
SDG 5 Gender equality
SDG 10 Reduced inequalities
SDG 16 Peace, justice and strong institutions

And the main bridge to the other clusters:
SDG 3 (Good health)

SDG 11 (Sustainable cities and communities) connects to research in all three clusters.

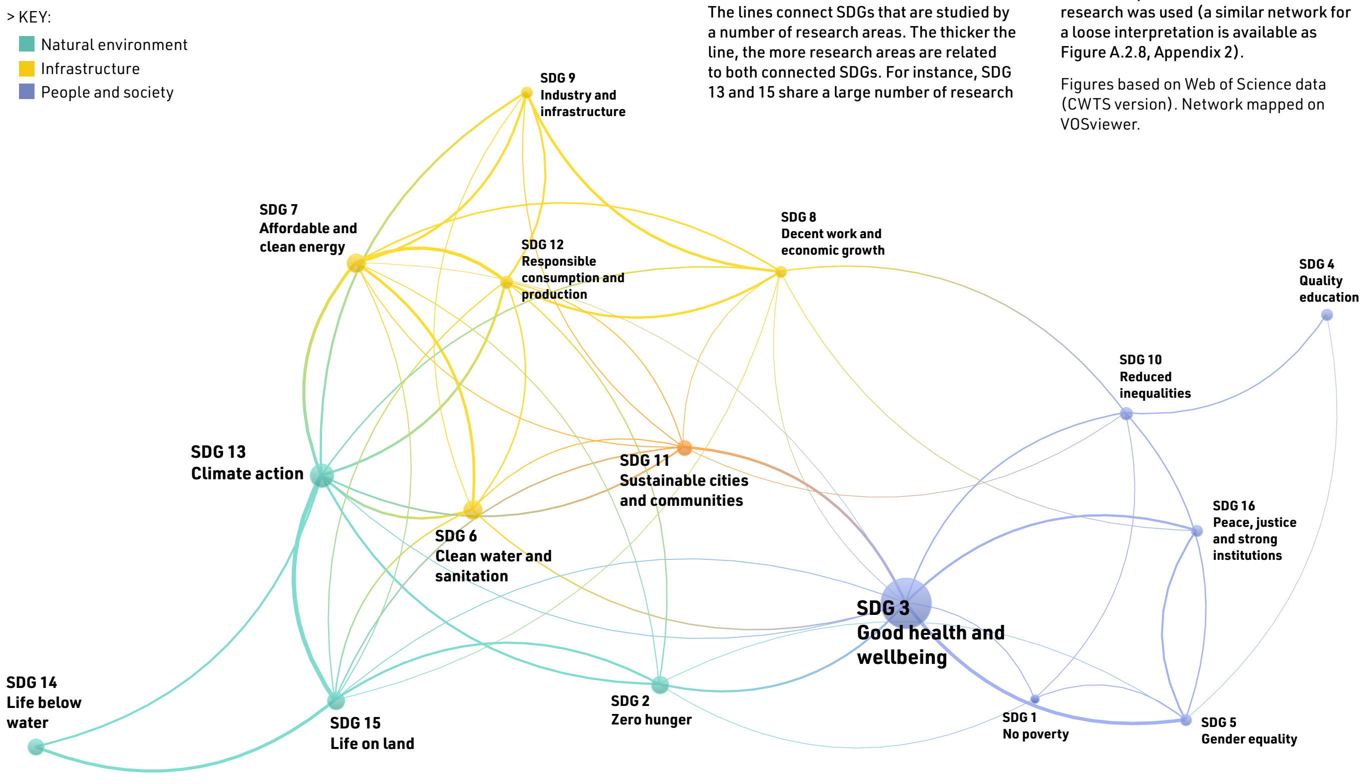
Figure 4.8 / Research synergies across SDGs

Each node identifies one SDG (the size of the node is proportional to the number of publications relating to that SDG). Each colour identifies one cluster of SDGs.

The lines connect SDGs that are studied by a number of research areas. The thicker the line, the more research areas are related to both connected SDGs. For instance, SDG 13 and 15 share a large number of research areas and publications, while SDG 4 shares only a small number of research areas and publications with SDG 10.

Strict interpretation of SDG-related research was used (a similar network for a loose interpretation is available as Figure A.2.8, Appendix 2).

Figures based on Web of Science data (CWTS version). Network mapped on VOSviewer.



– does not tend to be conducted in association with research related to the lilac cluster, and only to a limited extent in association with research related to the green cluster. There are, however, strong connections between research on SDG 9 and technological solutions for affordable and clean energy (SDG 7), decent work and economic growth (SDG 8) and responsible production and consumption (SDG 12).

The disconnects between research areas can be problematic as they limit the understanding of the complex underlying society-related issues that lie behind many SDG challenges. Our case studies (Chapters 8 and 9), for example, show that access to resources below water and on land (SDGs 14 and 15) is deeply connected to peace, justice and institutions (SDG 16), and that governance issues (SDG 16) and education (SDG 4), are central to addressing neglected diseases such as Chagas (SDG 3).

A typology of SDG research

We set out to understand the specific characteristics of SDG-related research, including whether it is more or less likely to have an impact than other research, and whether there are specific types of research that are more likely to be SDG-related and that research funders should therefore target to support the SDGs.

To understand whether research related to SDGs differs from non-SDG-related research in its potential for societal impacts,[33] we classified all publications according to the following four features:[34]

- **Collaborations and funding,** measured by the extent of international collaborations, access to funding, and collaboration with industry[35]
- **Academic reputation,** measured by standard indicators of academic citations[36]
- **Public and industry use,** measured by citations in patents, policy documents, news stories, and Twitter posts[37]
- **Open access and multidisciplinarity,** measured according to the share of publications that are open access and the Rao-Stirling diversity index of disciplines within research areas[38]

We measured the proportion of publications related to each SDG that possessed each of the above characteristics. This resulted in three clusters of SDGs, similar to those grouped by synergies described above (Figure 4.8).[39]

The features of each cluster are described below and illustrated in Figure 4.9.

Collaborations and funding

Overall, SDG-related publications are less likely (45% of publications) than the average publication in the WoS (54%) to acknowledge external funding. This differs for different clusters: 60% of publications relating to the natural environment and health SDGs acknowledge external funding, compared with 52% for the social functions and technical solutions cluster and just 31% for the people and society cluster. Even accounting for disciplinary differences in acknowledging funding, these figures point to difficulties in attracting research funding for the people- and society-related SDGs. This should be further investigated.

We also find differences in the extent of international collaborations. Publications related to natural environment and health SDGs are the most likely to be written in collaboration across countries (33%), including between HICs and other countries (15%) – more than those relating to social functions and technical solutions SDGs (27% and 15%) or the people- and society-related SDGs (23% and 9%), which are below the

LILAC	YELLOW	GREEN
A cluster of SDGs related to people and society	**A cluster of SDGs related to social functions and technical solutions**	**A cluster of SDGs related to the natural environment and health**
SDG 1 No poverty	**SDG 6** Clean water and sanitation	**SDG 13** Climate action
SDG 4 Quality education	**SDG 7** Affordable and clean energy	**SDG 14** Life below water
SDG 5 Gender equality	**SDG 11** Sustainable cities and communities	**SDG 15** Life on land
SDG 10 Reduced inequalities	**SDG 12** Responsible consumption and production	These share features with health publications
SDG 16 Peace, justice and strong institutions	Also including	**SDG 3** Good health
Also including	**SDG 2** Zero hunger	
SDG 8 Decent work and economic growth		
SDG 9 Industry, innovation and infrastructure		

> KEY: **Sustainable Development Goals**

SDG 1 No poverty
SDG 2 Zero hunger
SDG 3 Good health and well-being
SDG 4 Quality education
SDG 5 Gender equality
SDG 6 Clean water and sanitation
SDG 7 Affordable and clean energy
SDG 8 Decent work and economic growth
SDG 9 Industry, innovation and infrastructure
SDG 10 Reducing inequality
SDG 11 Sustainable cities and communities
SDG 12 Responsible consumption and production
SDG 13 Climate action
SDG 14 Life below water
SDG 15 Life on land
SDG 16 Peace, justice, and strong institutions
SDG 17 Partnerships for the Goals

WoS average (25% and 12%). The relatively low figures raise questions about the transfer of capabilities across countries in crucial areas of SDG-related research.[40]

SDG-related publications are substantially less likely to be produced in collaboration with industry than the average publication in the WoS (5% of publications). The highest levels of industry participation are in research related to the social functions and technical solutions SDGs (4%) and to SDG 3 (5%),[41] which is more focused on applied technological solutions.

Academic reputation

Publications related to the social functions and technical solutions SDGs and to industry, innovation and infrastructure (SDG 9) are more likely than the WoS average (13% versus 10%) to be in the top 10% most cited publications in their WoS category. For publications related to the natural environment and health SDGs and the people- and society-related SDGs, this measure of academic reputation is no different from the WoS average, with the exception of SDG 9.

Open access and multidisciplinarity

SDG-related publications are no more likely to be open access than the WoS average (43%). Only publications relating to the natural environment and health SDGs are slightly more accessible to all readers than average (50%), while those linked to people- and society-related SDGs (42%) and to social functions and technical solutions SDGs (39%) are less open access than average. These results indicate that there is a limited transfer of knowledge to those countries that most need to advance towards the SDGs and have limited research capacity and limited resources to access costly academic publications.

On the other hand, publications related to SDGs do have a higher degree of multidisciplinarity (52%) than the WoS average (43%). Publications connected to the people- and society-related SDGs are the most multidisciplinary (56%), followed by those related to social functions and technical solutions SDGs (52%) and natural environment and health SDGs (47%). This indicates that research related to people- and society-related SDGs may be better placed to address the complexity of SDG challenges.[42]

Public and industry use

SDG-related publications across all three clusters are used substantially more in policy reports (11% are used in this way), news articles (5%) and social media (40%) than the average publication in WoS (2%, 4% and 33% respectively). This is particularly the case for publications linked to the people- and society-related group of SDGs (25%, 7% and 48% of publications in the case of SDG 1, for example). Of all the SDG-related publications, those relating to the social functions and technical solutions SDGs attract the least policy (6%), media (3%) and social media (27%) interest.

Figure 4.9 / Characteristics of SDG-related publications

	CLUSTERS			
	SDGs 1, 4, 5, 8, 9, 10, 16	SDGs 2, 6, 7, 11, 12	SDGs 3, 13, 14, 15	
	People and society	Social functions and technical solutions	Natural environment and health	WoS average (%)
International collaborations	↓	=	↑↑	25%
Collaborations involving HICs	↓	↑↑	↑	11.7%
Funded	↓↓	=	↑	53.6%
Industry	↓↓↓↓	↓↓	↓↓	5%
Reputation	=	↑	=	10.3%
Use in patents	↓↓↓↓	↓↓	↓↓	0.4%
Use in policy	↑↑↑↑↑	↑↑↑	↑↑↑	2.4%
Use in news stories	↑↑	↓↓	↑↑	2.8%
Use on Twitter	↑↑	↓↓	↑	3.3%
Open access	=	↓	↑	43.3%
Multidisciplinarity	↑	↑	=	43.4%

The table illustrates, for 11 features, whether the share of publications in a given cluster of SDGs is higher (↑), lower (↓), or similar (=) to the average of all WoS publications. For example, for all three clusters, the share of publications authored with organisations from industry (Industry) is lower than the WoS average.

Indicators are defined as follows:

International collaborations: share of publications with an author from at least two countries

Collaborations involving HICs: share of publications with at least one author from a HIC and one author from any other income group

Funded: share of publications that acknowledge funding from any source

Industry: share of publications with at least one author from industry

Reputation: share of top 10% most cited publications in any WoS category

Use in patents: share of publications cited in patents

Use in policy: share of publications cited in policy reports

Use in news stories: share of publications mentioned in the news

Use on Twitter: share of publications mentioned in Twitter

Open access: share of publications in open access journals

Multidisciplinarity: Rao-Stirling diversity index based on WoS categories

> KEY:
- ↑ less than 50% higher than average
- ↑↑ 50-100% higher than average
- ↑↑↑ around 100% higher than average
- ↑↑↑↑ at least 4x higher than average
- = similar to the WoS average
- ↓ around 50% of the average
- ↓↓ between 50% and 33% of average
- ↓↓↓ between 50% and 33% of average
- ↓↓↓↓ less than 25% of average

Based on strict interpretation of SDG-related research. Figures based on Web of Science data (CWTS version).

These findings indicate that, in terms of the SDGs, research linked to the people- and society-related SDGs is of more immediate relevance than technical solutions to policy-makers and society. It might also be the case that basic science research and technical solutions are less likely to use terms related to SDGs, and are therefore less likely to be captured by our SDG-related queries.

We find the opposite pattern in relation to industry use of research. While all SDG-related publications are less likely to be cited in patents (0.1%) than the WoS average (0.4%), those relating to social functions and technical solutions SDGs are closer to the average (0.16%). The main exceptions are health-related publications, which are 50% more likely to be cited in patents than the WoS average (0.6%).

Overview and implications

Compared with the average publication in the WoS, and with the rest of SDG-related research, research linked to the people- and society-related SDGs is more used in policy, potentially more impactful in society, more multidisciplinary, and of at least as high quality.

Research related to the social functions and technical solutions SDGs is the most focused on basic sciences and technology applications, and the closest to industry. However, it does not attract much public or policy interest.

Research related to the natural environment and health SDGs is highly used in policy and society, attracts the most funding, and is most likely to be co-authored internationally and to be open access.

Taken together, these findings indicate a need for greater public funding for research that focuses on the complex societal determinants of sustainability, to complement, rather than follow, private funding.

Notes

1. Confraria and Wang, 2020; Yegros-Yegros et al., 2020.
2. Koning et al., 2021; Wallace and Ràfols, 2018.
3. Bromham et al., 2016.
4. Pinheiro et al., 2021.
5. Among others: Vanderfeesten and Otten, 2017; Colciencias, 2018; Nakamura et al., 2019; Wastl et al., 2020; Elsevier, 2020; LaFleur, 2019; Duran-Silva et al., 2019.
6. We use the location of the researchers rather than on the geography focus of the research, for which data is not systematically available.
7. See Figure A.2.4, Appendix 2.
8. See Armitage et al., 2020; Schmidt and Vanderfeesten, 2021 for evidence of radical differences in assigning publications to SDGs across different methods.
9. We excluded SDG 17 because it was not possible to identify a reliable set of terms related to this SDG.
10. Waltman and van Eck, 2012.
11. This research area is described with the following keywords: Gini index; poverty dynamic; deprivation; income mobility.
12. Chavarro et al., 2018; Ràfols et al., 2019.
13. See Figures S1-S16, Supplementary Figures for detail on the number and share of publications for individual countries and income groups for all SDGs.
14. See Figures S17-S32, Supplementary Figures for details of the organizations publishing in relation to each SDG and their contribution to global SDG-related research.
15. LICs are only slightly more represented in SDG-related collaborative research than in collaborations in all Web of Science collaborations (Appendix 2, Table A.2.2, panel A).
16. Evans et al., 2014; Kraemer-Mbula et al., 2020; Mormina, 2019; Mutapi, 2019; Yegros-Yegros et al., 2020.
17. Figures S1-S2, Supplementary Figures.
18. Mowery, 2012.
19. Hoogeveen and Pape, 2019; United Nations and World Bank, 2018.
20. Figure S16, Supplementary Figures.
21. To visualise the extent to which different SDGs relate to different disciplines, see Figures S33-S48, Supplementary Figures. Figure A.2.7, Appendix 2 plots the map of WoS categories with equal weights. Figures S49-S64, Supplementary Materials show details of each discipline's contributions to each SDG.
22. Table A.2.3, Appendix 2.
23. Table A.2.4, Appendix 2.
24. See Country clustering section (2.1.2) in Appendix 2 for method details. Tables A.2.5 and A.2.6, Appendix 2 show the value of each variable by cluster and by country. Figure A.2.6, Appendix 2 plots the hierarchical clustering dendrogram (distance between clusters).
25. Mainly Arab states of the Persian Gulf and Eastern European countries.
26. Among the publications related to SDG3, according to the strict interpretation of SDG-related research, 27% can be connected to a disease.
27. This may also be due to our method to assign publications to the SDGs, which relies on terms more commonly used in social sciences. See Chapter 12.
28. Independent Group of Scientists appointed by the Secretary-General, 2019.
29. Barbier and Burgess, 2019; Le Blanc, 2015; Nilsson et al., 2016.
30. Figure A.2.9, Appendix 2.
31. Figures A.2.10 and A.2.11, Appendix 2, show details of these research areas. To explore the research areas, please see web tool discussed in Chapter 12.
32. See Synergies section (2.1.3), Appendix 2 for a description of methods.
33. Bornmann, 2013; Molas-Gallart et al., 2002.
34. See Table A.2.7, Appendix 2 for detailed figures for each SDG.
35. Confraria and Vargas, 2017; Confraria and Wang, 2020; Etzkowitz and Leydesdorff, 2000.
36. Kraemer-Mbula et al., 2020; Yin et al., 2021.
37. Noyons, 2019; Yin et al., 2021.
38. Årdal and Røttingen, 2012; Arza and Fressoli, 2018; Bromham et al., 2016; Poole et al., 2021.
39. The similarity of these clusters to those based on synergies, described above (Figure 4.8), suggests robustness of our methods, and that research areas that overlap (synergies) also share similar characteristics.
40. Mormina, 2019.
41. Table A.2.7, Appendix 2.
42. Messerli et al., 2019; UNESCO, 2021.

> CHAPTER 5

A global map of technological inventions

Mapping and characterizing SDG-related patenting activity across the world

AUTHORS

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Footnotes for this chapter are on page 71. A full list of references can be found on page 140.

OVERVIEW

This chapter maps inventions that are of potential relevance for specific SDGs.

Key findings include:

- Only a tiny share (1.9%) of patented inventions between 2001 and 2017 were related to the SDGs
- SDG-related inventions mainly focus on SDG 3, SDG 7 and SDG 6, and include market solutions such as drugs and solar panels
- Most inventions are generated in high-income countries and in upper-middle income countries
- Inventions filed in low-income countries often originate in higher-income countries
- Most SDG-related inventions focus on a single SDG, with only a tiny fraction addressing synergies and trade-offs between SDGs
- The use of patents can prevent others from using a particular innovation to address sustainability challenges

Introduction

This chapter maps SDG-related inventions between 2001 and 2017. It analyses the countries and technology fields involved, and the connections between SDGs.

Inventions and patent authorities play a central role in contributing to SDG 9 (Industry, innovation and infrastructure) by building new technologies.[1,2] Inventions contribute to the other SDGs in various ways: not only through new products and services based on patented inventions, but also by increasing the pool of technical knowledge available to society. In this chapter, we look beyond countries' overall rates of innovation, (number of patents) and focus on the direction of innovative activity (content of patents).

Which SDGs attract the most inventions?

Using the method developed in this study, we found that 369,253 unique inventions produced from 2001 to 2017 were related to SDGs. This represents just 2% of all inventions produced worldwide in that timeframe.

Three SDGs accounted for the vast majority of SDG-related inventions, as follows:

- SDG 3: Good health and well-being (229,529; 62%)
- SDG 7: Affordable and clean energy (58,230; 16%)
- SDG 6: Clean water and sanitation (39,443; 11%)

Only a small proportion of SDG-related inventions were related to the other SDGs: SDG 12 (7% of all SDG-related inventions); SDG 11 (3%); SDG 2 (2%); SDG 15 (2%); SDG 13 (1%); SDG 14 (0.6%); and SDG 4 (0.1%).

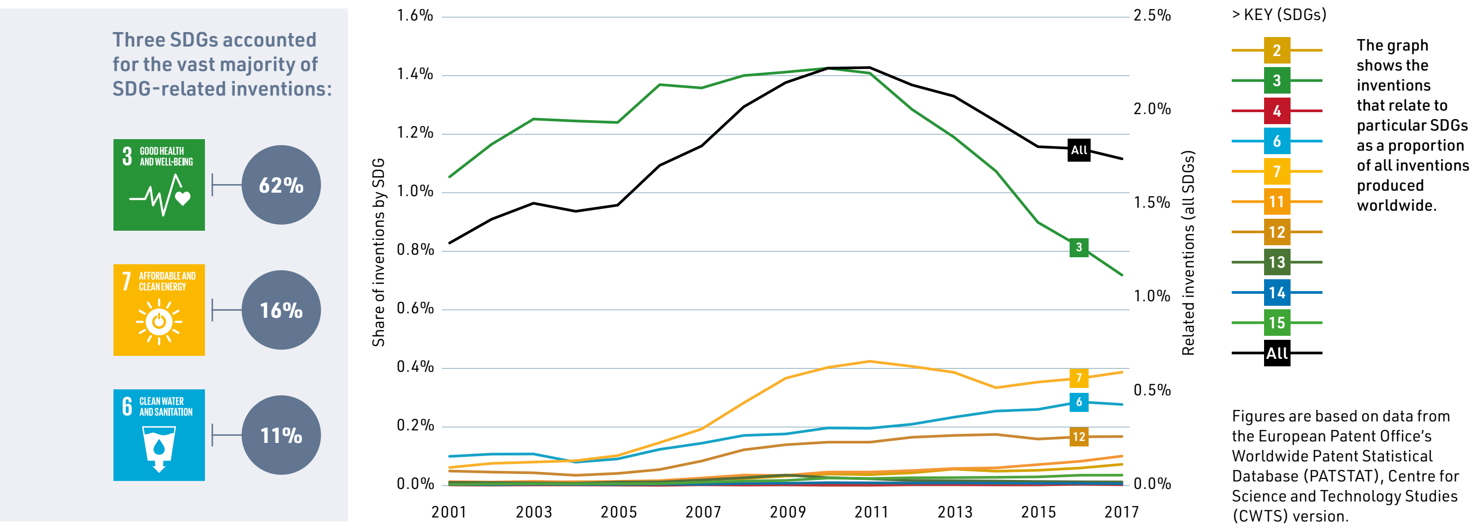
Figure 5.1 shows how the proportion of inventions related to SDG 3 has decreased since reaching a peak in 2010-2011, while the proportions relating to other SDGs have increased, especially since 2005.

Which countries focus most on SDG-related inventions?

Inventions in low income countries (LICs) are more likely to relate to SDGs than those in other country groups, as shown in Figure 5.2. When we consider all patents for which we have information about the country of the inventor, approximately 9% of LIC inventions are SDG-related, compared with 6% of inventions in lower-middle income countries (LMICs), 3% in high-income countries (HICs) and 2% in upper-middle income countries (UMICs). However, the absolute number of inventions in LICs is just 60, compared with 224,019 in HICs.

These differences between country groups remain when we consider the country in which the patent was filed, rather than the country of the inventor.[3] The African Regional Intellectual Property Organization (ARIPO) is the patent authority with the highest percentage of inventions related to any of the SDGs (24%).[4]

Figure 5.1 / Share of inventions related to different SDGs (2001-2017)



Figures are based on data from the European Patent Office's Worldwide Patent Statistical Database (PATSTAT), Centre for Science and Technology Studies (CWTS) version.

The World Intellectual Property Organization (WIPO) and European Patent Office (EPO) have a higher share of SDG-related inventions (6%) than other authorities in HICs, such as the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO) (3% and 2%, respectively). At the China National Intellectual Property Administration (CNIPA), which dominates patenting activities among UMICs, around 2% of inventions are related to the SDGs.

Despite ARIPO's relatively high percentage of SDG-related inventions, the absolute number of inventions filed at ARIPO represents a tiny fraction of worldwide SDG-related inventions: just 1,673, compared with more than 180,000 at CNIPA or USPTO[5] in the same period.

Across country groups, the share of SDG-related inventions began to increase in 2005 and then declined after 2011. The number of SDG-related inventions produced in LICs has fluctuated over time, while numbers in the other three country groups have been much more stable.

SDG focus within country groups

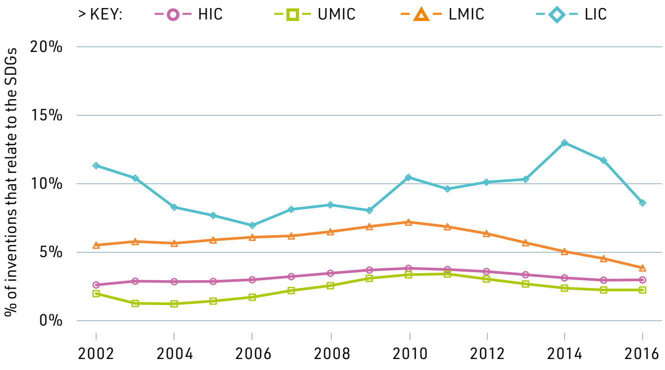
SDG 3 accounts for the highest share of SDG-related inventions in all country groups, as shown in Figure 5.3. However, compared with other country groups, UMICs produce a lower proportion of SDG 3-related inventions and a higher proportion of inventions related to SDG 7. This pattern is driven by the role of China in developing renewable technologies.

The SDG with the second-highest percentage of inventions is SDG 7 in HICs, UMICs and LMICs, and SDG 6 in LICs. SDG 6 has also been the focus of a relatively high share of inventions in HICs, UMICs and LMICs.

This pattern is confirmed when considering the patent authority, rather than the country of the inventor.[6] SDG 3 accounts for the highest share of SDG-related inventions in all patent authorities, ranging from 47% in CNIPA to 86% at the EPO. SDG 7 accounts for the second-highest percentage of SDG-related inventions across patent authorities. CNIPA has a substantially higher proportion of inventions related to SDG 7 (20%) and SDG 6 (13%) than all other patent authorities (less than 10% for both SDGs).

The other SDGs account for a much lower share of inventions across all income groups and patent authorities. In particular, LICs did not file any patents related to SDG 2, SDG 4, SDG 13 or SDG 14.

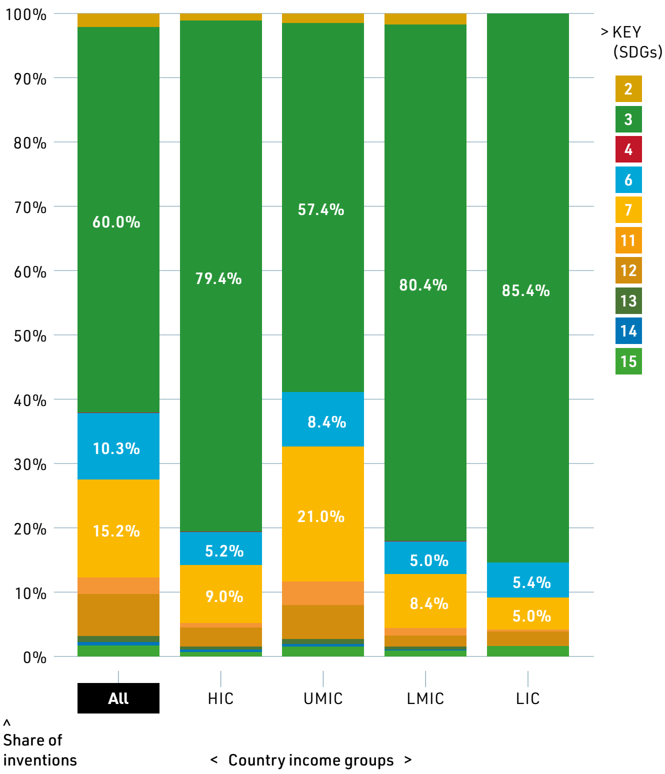
Figure 5.2 / SDG-related inventions in different income groups (2001-2017)



The graph shows the proportion of inventions that relate to any of the SDGs in the study. For each year, we show the average over a three-year period (for example, for 2002, we show inventions from 2001-2003). Figures are based on the total number of inventions in countries in each of the four World Bank income groups (2021 definition): high-income countries (HIC); upper-middle income countries (UMIC); lower-middle income countries (LMIC); low-income countries (LIC).

Figures based on PATSTAT data (CWTS version).

Figure 5.3 / Inventions related to the SDGs by country group (2001-2017)



The chart (right) shows the proportion of SDG-related inventions that relate to each SDG for each country group. Data is shown for each group of countries, defined according to World Bank income group classifications: high-income countries (HIC); upper-middle income countries (UMIC); lower-middle income countries (LMIC); and low-income countries (LIC).

Figures based on PATSTAT data (CWTS version).

Identification of SDG-related inventions: our methods

Our strategy to identify SDG-related patents builds on the methodology we used to identify SDG-related scientific publications (chapter 4).

We first retrieved all patent applications filed between 2001 and 2017 in one or more of the most important national and regional patent authorities worldwide.[7]

- African Regional Intellectual Property Organization (ARIPO)
- China National Intellectual Property Administration (CNIPA)
- European Patent Office (EPO)
- Japan Patent Office (JPO)
- Korean Intellectual Property Office (KIPO)
- United States Patent and Trademark Office (USPTO)
- World Intellectual Property Organization (WIPO)

By selecting several authorities, we minimized the possibility of bias due to the propensity of inventors to file patents in their own country. The rationale for looking beyond some of the largest patent authorities (USPTO, EPO and JPO) was to increase the chances of capturing the inventive activity of at least some lower-middle income countries (LMICs) and low-income countries (LICs).

We then identified which of these patents cited at least one SDG-related scientific publication (see chapter 4).

We also searched the titles and abstracts of patents (when an English version was available) with the same keywords used to identify SDG-related publications.[8]

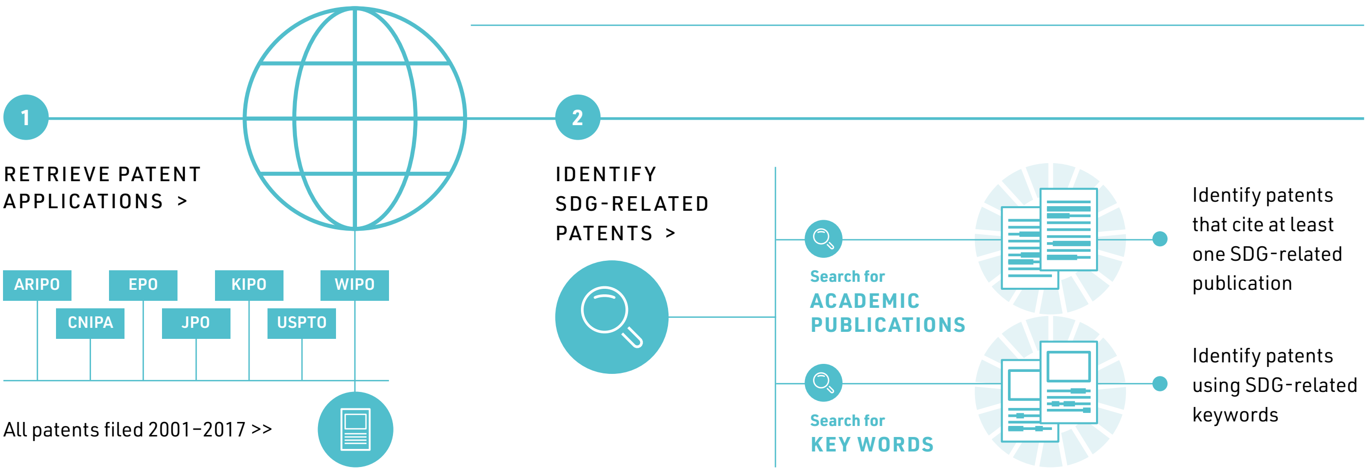
This method is purposefully restrictive. Not all patents that are relevant to SDGs will cite SDG-related publications (the number of patents citing any publications is very low, as discussed in chapter 4). Moreover, patents use technical language to describe inventions thus, even where inventions are potentially relevant for achieving the SDGs, they might not include keywords that relate directly to the goals. The results in this chapter are therefore based on a conservative interpretation of which inventions are related to SDGs. Because our study compares shares of inventions across SDGs, countries and technology fields, we believe a conservative interpretation produces a more accurate analysis than a method that privileges coverage over precision.

To avoid double-counting, we grouped SDG-related patent applications into simple 'patent families'. Each family represented a unique invention, whose protection may have been sought in multiple patent authorities. We then performed our analyses at the level of these patent families.[9]

SDGs included in the analysis

Because patented technologies are less likely to be directly relevant for the SDGs that address social and political issues – such as poverty, gender and economic inequalities, economic growth, and violent conflict – we included only the following SDGs in this analysis: 2, 3, 4, 6, 7, 11, 12, 13, 14 and 15.

This was based on our initial manual assessment of the relevance of International Patent Classification codes for each SDG.[10]



Changes in focus over time

In LICs, the main focus on SDG 3 has remained relatively stable over time. However, efforts to develop inventions related to other SDGs seem to have taken off since 2008, as shown in Figure 5.4, with some fluctuations over time due to the small number of inventions.

In LMICs, inventions related to SDG 6 and SDG 3 steadily increased up to 2012, when they started to decline. Inventions related to most other SDGs increased from around 2006/2007. Figures for LMICs are mainly driven by India, which files most of the LMIC patents.

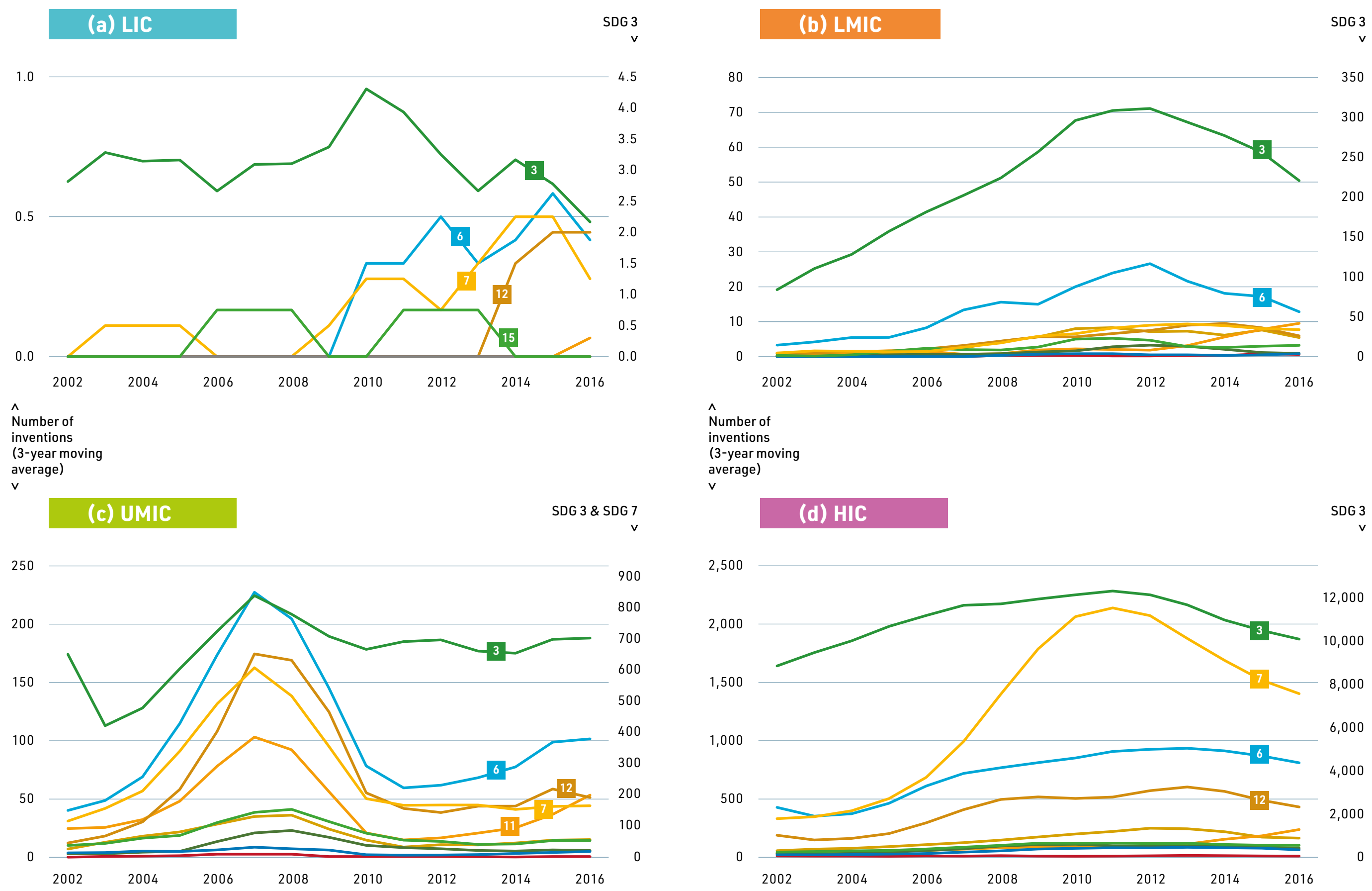
In UMICs, inventions related to many of the SDGs increased rapidly until 2006/2007, when they began to fall before rising again in recent years. These trends are clearly influenced by China,[11] which develops roughly 80% of all UMIC inventions.

Inventions in HICs are characterized by relatively stable and continuous growth until 2012. Inventions related to several SDGs have stagnated since 2014, with some (including SDGs 3, 7 and 12) declining. A notable exception is SDG 11 (Sustainable cities and communities), which has experienced sustained growth since 2013.

Countries' technological capabilities

Roughly 90% of all SDG-related inventions worldwide have been developed by inventors in HICs, while 8% were developed by inventors in UMICs. A similar concentration of inventive activity also exists within income groups. For example, 80% of SDG-related inventions in HICs were developed by just 6 of the 73 HICs, and the United States alone developed 47% of all HIC SDG-related inventions.

Figure 5.4 / Number of SDG-related inventions by income group (2002-2016)



The charts show the number of SDG-related inventions by year for each SDG. For each year we considered the average over a three-year period (for example, for 2002, we considered inventions from 2001-2003). Each panel refers to one of the four World Bank income groups: high-income countries (HIC); upper-middle income countries (UMIC); lower-middle income countries (LMIC);and low-income countries (LIC). Figures based on PATSTAT (CWTS version).

> KEY: **Sustainable Development Goals**
- **SDG 2** Zero hunger
- **SDG 3** Good health and well-being
- **SDG 4** Quality education
- **SDG 6** Clean water and sanitation
- **SDG 7** Affordable and clean energy
- **SDG 11** Sustainable cities and communities
- **SDG 12** Responsible consumption and production
- **SDG 13** Climate action
- **SDG 14** Life below water
- **SDG 15** Life on land

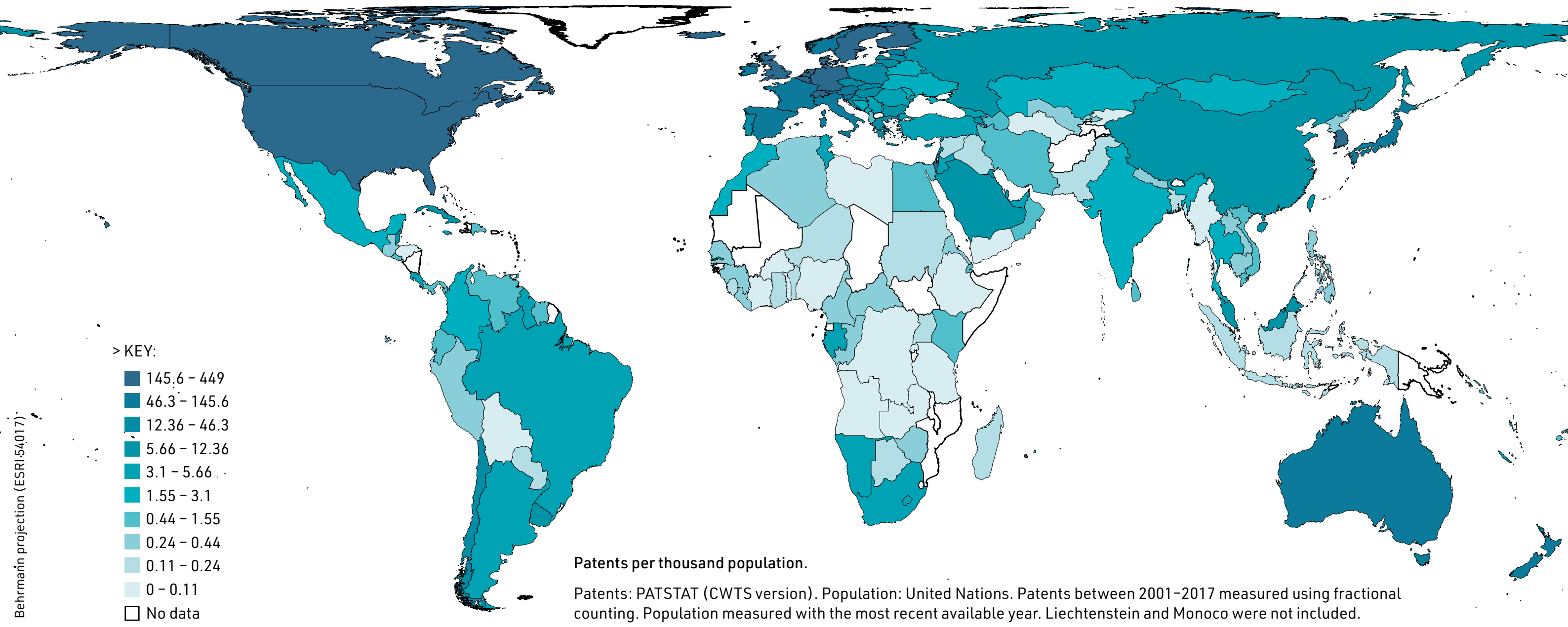
The disparity between countries is even more extreme in middle-income countries. China alone, for example, developed around 80% of the SDG-related inventions in UMICs, while India accounts for roughly 85% of the SDG-related inventions from LMICs. Details of SDG-related inventions by country can be found in Appendix 3.

When we consider inventions per capita (see Figure 5), smaller countries such as Switzerland, Denmark, Singapore, Israel and Sweden stand out in terms of their SDG-related inventive activity. However, the most scientifically and technologically advanced countries, including the United States, Canada, Germany, France, United Kingdom, Australia, Japan and South Korea, also produce a high number of inventions per capita.

Collaborations between countries

Collaborations between two or more countries account for only 13% of all those SDG-related inventions for which we have information about the inventor's country. As shown in Table 5.1a, roughly 91% of all collaborations involve HICs and/or UMICs, while 83.1% are exclusively between HICs. The

Figure 5.5 / SDG-related inventions per capita (2001-2017)



Patents per thousand population.

Patents: PATSTAT (CWTS version). Population: United Nations. Patents between 2001–2017 measured using fractional counting. Population measured with the most recent available year. Liechtenstein and Monoco were not included.

Do patents and the patent system contribute to or prevent the achievement of SDGs?

Patented inventions can contribute to achieving the SDGs in two key ways:

- Through the use of knowledge embodied in patents to commercialize products or services
- By disseminating technical information through patent documents, thus inspiring subsequent inventions (technical information is freely available for most patent applications and granted patents)

On the other hand, the patent system can prevent the use of inventions by anyone who does not have patent rights. This potentially prevents many people from benefiting from protected inventions. Such barriers became prominent, for example, during the AIDS crisis in South Africa in the 1990s and during the contemporary COVID-19 pandemic.[12, 13]

Moreover, patents do not necessarily equate to innovation. Many inventions protected by patents have not yet been translated into new products or services. Instead, many patented inventions represent, at best, promising technologies in an embryonic status, which may take a long time to develop. Development often requires substantial financial investment, usually by private firms whose objectives do not always align with SDGs.

In the rare cases that products or services based on SDG-related inventions are brought to market, there remains the serious challenge of making these products available in countries that currently lack basic infrastructures.

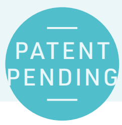


Table 5.1a / Collaborative SDG-related inventions within and between each country group (as a percentage of all collaborative inventions), 2001-2017

COUNTRY GROUPS	HIC	UMIC	LMIC	LIC
HIC	83.1%			
UMIC	7.9%	3.7%		
LMIC	3.3%	0.3%	1.5%	
LIC	0.1%	0%	0%	0%
TOTAL	29,609.3 (84.6%)	3,731.6 (10.7%)	1,602.9 (4.6%)	47.8 (0.1%)

Table 5.1b / Collaborative SDG-related inventions within and between each country group (as a percentage of collaborative inventions within each income group), 2001-2017

COUNTRY GROUPS	HIC	UMIC	LMIC	LIC
HIC	88.0%	8.4%	3.5%	0.1%
UMIC	66.7%	31.0%	2.2%	0.1%
LMIC	65.2%	5.1%	29.6%	0.0%
LIC	65.2%	7.7%	0.6%	30.0%

1a: This shows what proportion of all collaborative inventions occurred within (diagonal) and between (off the diagonal) country groups. For example, an invention co-developed by authors in the USA and the UK (both HICs) would contribute to the percentage in the top left cell. An invention co-developed by inventors in the USA and Brazil (between HIC and UMIC) would contribute to the second row of the first column. The sum of all cells equals 100%, that is, all the inventions co-developed by two or more countries (based on the country of the inventor).

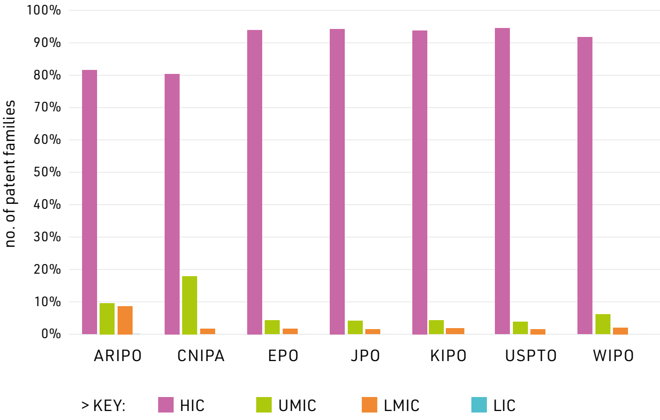
1b: This shows what proportion of the collaborations within each country group occurred within and between country groups. For example, the first row shows the country groups involved in all collaborative inventions undertaken by HIC. Each row total adds up to 100%.

Figures are based on PATSTAT data (CWTS version), 2001-17.

most frequent collaborations between different income groups involve HICs and UMICs (7.9%), followed by those involving HICs and LMICs (3.3%). These collaboration patterns indicate that the less scientifically and technologically developed countries rarely participate in developing joint inventions.

Table 1b shows that HICs are involved in most collaborative inventions produced in all other country groups. The majority (more than 60%) of collaborations in UMICs, LMICs and LICs involve HICs, with very few collaborations between LICs, LMICs or UMICs. As noted, these collaborations

Figure 5.6 / SDG-related inventions by income level of the country of the inventors



The chart shows, for each of the patent authorities considered in the study, the percentage of SDG-related inventions filed by each of the country groups: HICs in blue, UMICs in orange, LMICs in grey and LICs in yellow.

Figures are based on PATSTAT data (CWTS version), 2001-17.

represent a low number of inventions as SDG-related inventive activity is highly concentrated in HICs and UMICs.

LICs and LMICs may gain knowledge and technological capabilities through their collaborations with HICs. However, such collaborations may also indicate a dependence on the focus and priorities of HICs, which may make it less likely that the inventions and related knowledge will address LICs' needs.

Inventions by country group across patent authorities

Dominance by richer nations is confirmed by the evidence that HICs generate more than 80% of SDG-related inventions in most patent authorities, including ARIPO (Figure 5.6). CNIPA is the only exception, in part due to the large percentage of inventions at this office for which the inventor's country is not available (58%).[14] UMIC inventive activity is more modest. UMICs generated around 18% of the SDG-related inventions at CNIPA, and between 4% and 10% in other authorities.[15, 16]

The inventive activity of LICs is hardly visible in any patent authority. These countries were involved in developing just 0.1% of the inventions registered at ARIPO, and their activity is even lower in the other patent authorities.

Technologies underpinning SDG-related inventions

Our analysis of the technologies that underpin SDG-related inventions (Figure 5.8) is based on the technology classification developed by Ulrich Schmoch,[17] which maps the International Patent Classification in 35 technology fields. The predominant technical fields relating to each of the SDGs are shown in Figure 5.7. In the next subsection we investigate the extent to which technology fields are related to different SDGs.

Figure 5.7 / Some of the main technology fields associated with each SDG

SDG 2: Other special machines (inc. food productionand harvesting) and **Basic materials chemistry** (inc. fertilizers, pesticides and herbicides)

SDG 3: Pharmaceuticals (preparations for medical purposes) and **Biotechnology**

SDG 4: Control (inc. appliances and devices designed for education, teaching and training)

SDG 6: Environmental technology (inc. filters, waste disposal, water cleaning, waste combustion or noise-absorption walls)

SDG 7: Electrical machinery, apparatus, energy (including non-electronic) and **Thermal processes and apparatus**

SDG 11: Civil engineering (inc. locks, plumbing etc); **Environmental technology**; **Control**; and **Digital communication**

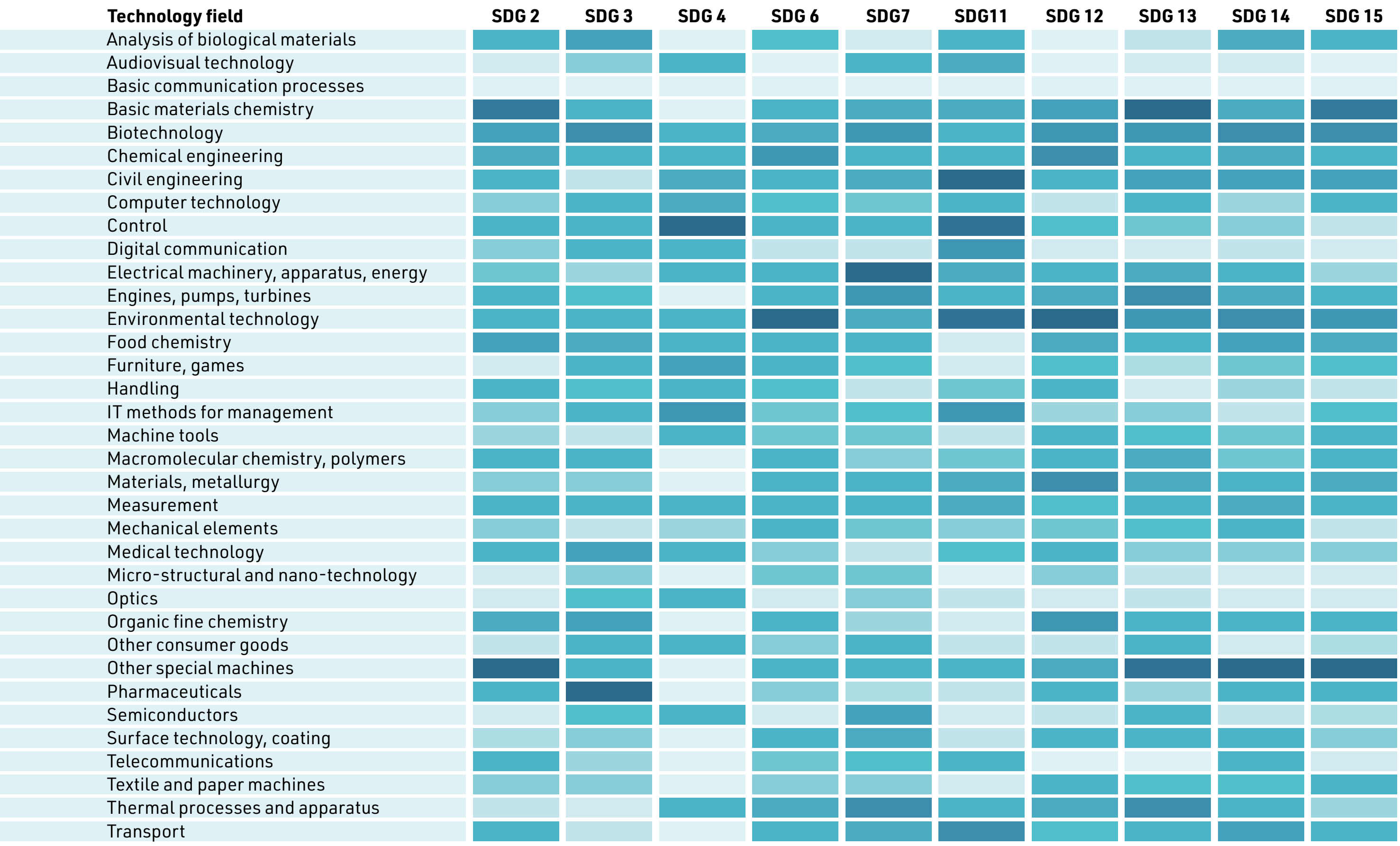
SDG 12: Environmental technology and **Materials, metallurgy** (including metals, ceramics, glass)

SDG 13: Basic materials chemistry: engines, pumps, turbines (including non-electrical engines); and **Other special machines**

SDG 14: Other special machines and **Environmental technology**

SDG 15: Other special machines and **Basic materials chemistry**.

Figure 5.8 / Breakdown of inventions by technology field in each SDG



The figure shows the relative relevance of each of the 35 technology fields for each of the SDGs, based on the number of patent families within each SDG that relate to that technology. In darker blue are the technology areas that are most relevant for the SDG. For instance, for SDG3, the most relevant technology areas are pharmaceuticals and biotechnology. In pale blue are those technology areas which appear less relevant for each of the SDGs. Colours are not comparable between SDGs. Figures are based on PATSTAT data (CWTS version), 2001-17. The correspondence between the International Patent Classification and the 35 technology fields is fully integrated in PATSTAT.

> KEY:
: Most relevant
Least relevant :

Synergies across SDGs in inventive activities

We investigated the connections between the different SDG-related inventions in two ways. First, we analysed how many inventions relate to more than one technology field (Figure 5.9) and, second, how many inventions relate to more than one SDG.

Inventions related to more than one technology field

We identified three main clusters of technology fields, based on co-occurrences of inventions in different technologies. The clusters are as follows:

1. **Biotech** (including all pharmaceutical production)
2. **Chemistry** (food and basic)
3. **Engineering** (from machines to computers, including medical and environmental technologies)

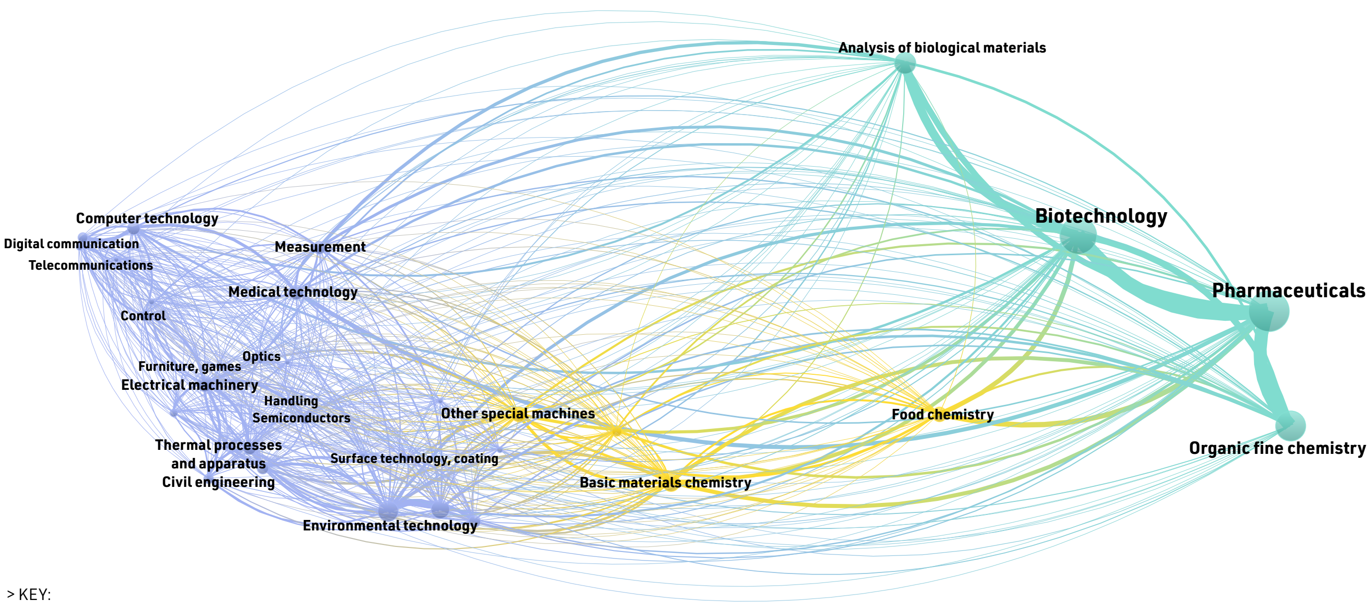
Due to the high number of inventions related to SDG 3 (Good health and well-being), many SDG-related inventions involve pharmaceuticals and biotechnology, analysis of biological materials and organic fine chemistry. Inventions related to SDG 3 often combine all three of these technologies. Far fewer SDG 3-related inventions involve the other technology fields such as medical technologies and food chemistry.[18]

Inventions related to other SDGs also combine different technology fields. For instance, inventions linked to SDG 2 (Zero hunger) tend to combine food chemistry and basic material chemistry for soil productivity, as well as special machines for agriculture and biotechnology for seed breeding. Inventions related to SDG 11 (Sustainable cities and communities) tend to combine even more technologies, including civil engineering, transport, telecommunications, environmental technologies, information technologies and control systems for smart cities.[19]

Inventions related to more than one SDG

We also studied the few inventions (3%) that are related to more than one SDG (see Figure 5.10). Developing inventions that relate to more than one SDG may help inventors to consider synergies and tensions between the goals. Figure 5.10 shows the strength of the relationships between SDGs: for example, SDG 4 appears isolated from other SDGs (except for weak connections with SDG 3, SDG 7 and SDG 15), while inventions related to SDG 3 are more likely to be connected with many other SDGs.

Figure 5.9 / Co-occurrence of technology fields across inventions



> KEY:
- **Biotech** (includes all pharmaceutical production)
- **Chemistry** (food and basic)
- **Engineering** (from machines to computers, including medical and environmental technologies)

The figure shows the co-occurrence of the 35 technology fields across SDG-related inventions. The size of each node is proportional to the number of inventions related to that technology. The thickness of the lines is proportional to the number of inventions related to two technology fields simultaneously. Technology fields of the same colour are more similar than technology fields of a different colour. This clustering has been created with the Leiden cluster algorithm implemented in VoSviewer. Appendix 3 includes figures for each co-occurrence network, showing how inventions related to each of the SDGs are linked to the 35 technology fields.

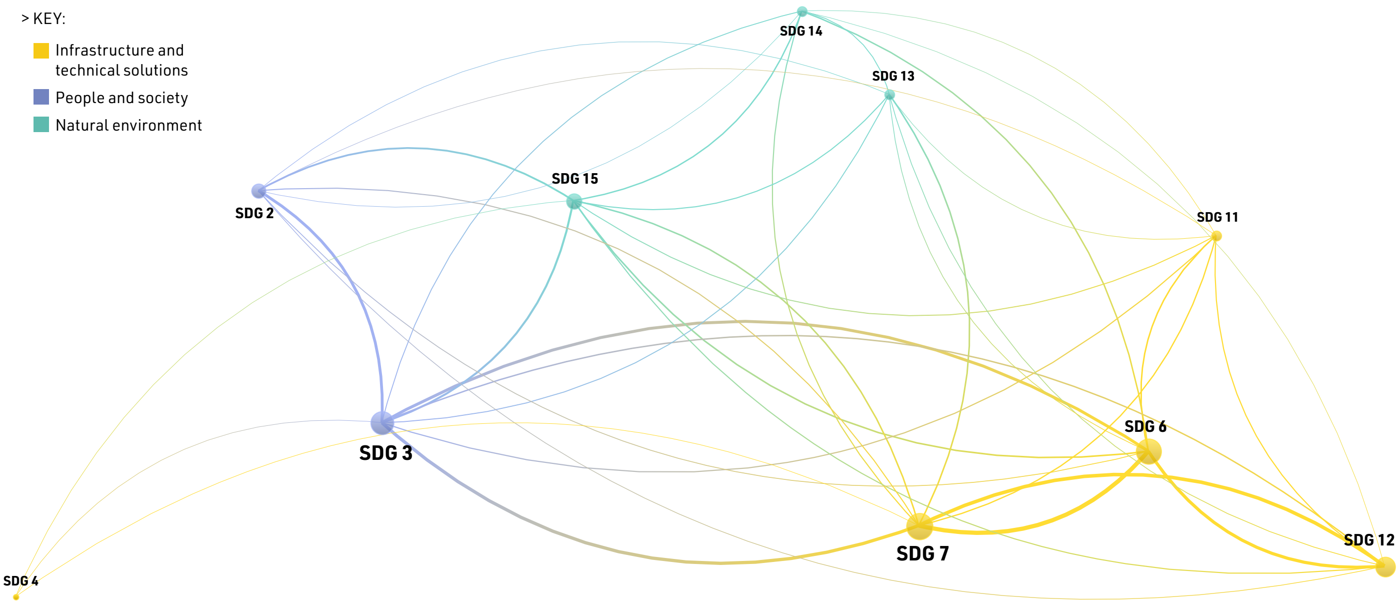
The figure is based on PATSTATdata (CWTS version), 2001-17. The correspondence between the International Patent Classification and the 35 technology fields is fully integrated in PATSTAT.

The analysis reveals three small clusters of related SDGs, similar to those found for research publications (chapter 4).

- The first cluster focuses on infrastructures and technical solutions. It contains inventions related to SDG 7 (Affordable and clean energy), SDG 6 (Clean water and sanitation), SDG12 (Responsible consumption and production) and SDG 11 (Sustainable cities and communities).
- The second cluster connects inventions related to people and society, linked to SDG 3 (good health and well-being) and SDG 2 (zero hunger).
- The third cluster contains inventions related to the natural environment, which link SDG 13 (Climate action), SDG 14 (Life below water) and SDG 15 (Life on land).

Despite these interconnections between SDGs, only a very small number of patents are related to more than one SDG. This casts doubt on the ability of inventions to tackle the complexity of synergies and tensions between the SDGs.

Figure 5.10 / Co-occurrence of SDGs among inventions



The figure shows the co-occurrences of SDGs among inventions. Each node identifies one SDG. The size of the node is proportional to the total number of inventions related to that SDG which are also related to at least one other SDG.

The thicker the line between two SDG nodes, the more inventions are related to both SDGs. SDGs of the same colour are more similar than SDGs of a different colour. This clustering has been created with the Leiden clustering algorithm, implemented in VoSviewer.

Figures are based on PATSTAT data (CWTS version), 2001-17.

Notes

1. European Union, 2021.
2. https://www.wipo.int/sdgs/en/story.html
3. Appendix 3, Table A.3.1.
4. Appendix 3, Figure A.3.1.
5. Appendix 3, Table A.3.1.
6. Appendix 3, Figure A.3.2.
7. We used the 2020 Autumn Edition of PATSTAT.
8. Chapter 4 and related Appendix 2.
9. Patent families are sets of patents that are filed in more than one country/office, to protect a single invention in several countries.
10. Appendix 3, section 3.1 details the procedure used to select SDG-related inventions.
11. There is a similar pattern when all inventions (not only those relating to SDGs) are considered, with a peak in 2007 and a decrease until 2010. However, this trend most likely reflects a lack of data about the inventor for a large percentage of patent families at the CNIPA.
12. https://www.bloomberg.com/news/articles/2021-05-11/aids-drugs-in-south-africa-shows-precedent-for-overriding-patents-on-medications
13. https://www.nature.com/articles/d41586-021-01242-1
14. Appendix 3, section 3.4.
15. The activity of UMICs at CNIPA is most likely underrepresented in this study , due to the large percentage of inventions at this office for which the country of the inventor is not available. Chinese inventors are much more active in their domestic patent office.
16. de Rassenfosse, G., & Seliger, F., 2021.
17. Schmoch, U., 2008.
18. Appendix 3, Figure A.3.4.
19. Appendix 3, Figure A.3.8.

> CHAPTER 6

STI-SDG alignment across countries

How research priorities relate to countries' SDG challenges

AUTHORS

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OVERVIEW

- We developed new methods to analyse the alignment between countries' research priorities and their SDG-related challenges.
- We found that countries with higher challenges relating to SDG 1 (No poverty), SDG 2 (Zero hunger), SDG 3 (Good health) and SDG 6 (Clean water and sanitation) are prioritizing research in these areas.
- For all other SDGs, we found a misalignment or inconclusive relationship between research priorities and SDG challenges.
- For example, the countries with the most unsustainable consumption/production patterns, and which contribute most to biodiversity loss, are usually higher-income countries that do not specialize in research related to SDG12 (Responsible consumption and production), SDG13 (Climate action) or SDG15 (Life on land).

Footnotes for this chapter are on page 78. A full list of references can be found on page 140.

Introduction

This chapter analyses the extent to which countries' research priorities align with their most significant SDG challenges and whether misalignments are worse in certain SDGs than in others.

Although the type of research that contributes to meeting an SDG target depends on the context and on the complex interactions between science and society, 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.

This assumption builds on the work of Pavitt,[1] who argued that the main practical benefit of scientific research is not the production of easily transmissible information, ideas and discoveries, but rather the construction of a problem-solving capacity. This capacity involves the transmission of often tacit knowledge through training and face-to-face interactions. Therefore, the benefits of research tend to be geographically localized, meaning each country needs its own pool of researchers who belong to international professional networks and exchange new scientific knowledge.[2] Moreover, SDG-related research undertaken by local researchers can help to inform local policy decisions through an understanding of context and different pathways to solve challenges.

The findings presented in this chapter can help guide and rebalance research priorities towards generating research capabilities that can address countries' major challenges.

Alignment patterns for individual countries

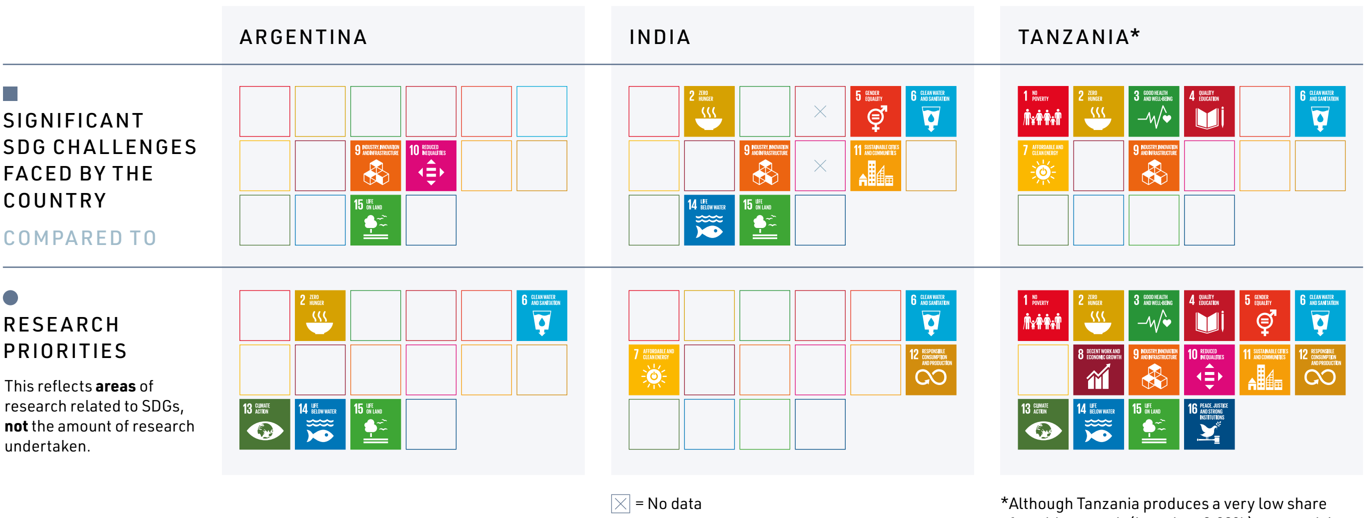
We calculated the relations between research priorities and SDG challenges for all countries where data was available. The cases of Argentina, India and Tanzania described below (and in Figure 6.1) illustrate some of the varying issues we found.

Argentina

In Argentina (an upper-middle income country), we found a low alignment between research priorities and SDG challenges. The country faces significant challenges in relation to SDG 9, SDG 10 and SDG 15 yet its research priorities relate to SDG 2, SDG 6, SDG 13, SDG 14 and SDG 15.

The high level of research specialization in SDG 2 is surprising since hunger is not a major problem in Argentina. This focus might be related to Argentina's strong trade in cereal, soya and meat production, and the consequent importance of agricultural productivity for the economy.

Figure 6.1 / SDG challenges and research priorities in Argentina, India and Tanzania: a visual comparison



*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.

Figure 6.2 / SDG challenges and research priorities in Argentina, India and Tanzania: a graphical comparison

Left hand column:

SDG SCORE (CHALLENGES) 2008-2017

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. See 'Our methods and approach', p75 for an explanation.

*Some scores were not calculated as some countries do not have data available for certain SDG indicators (for example, India for SDG 4 and SDG 10).

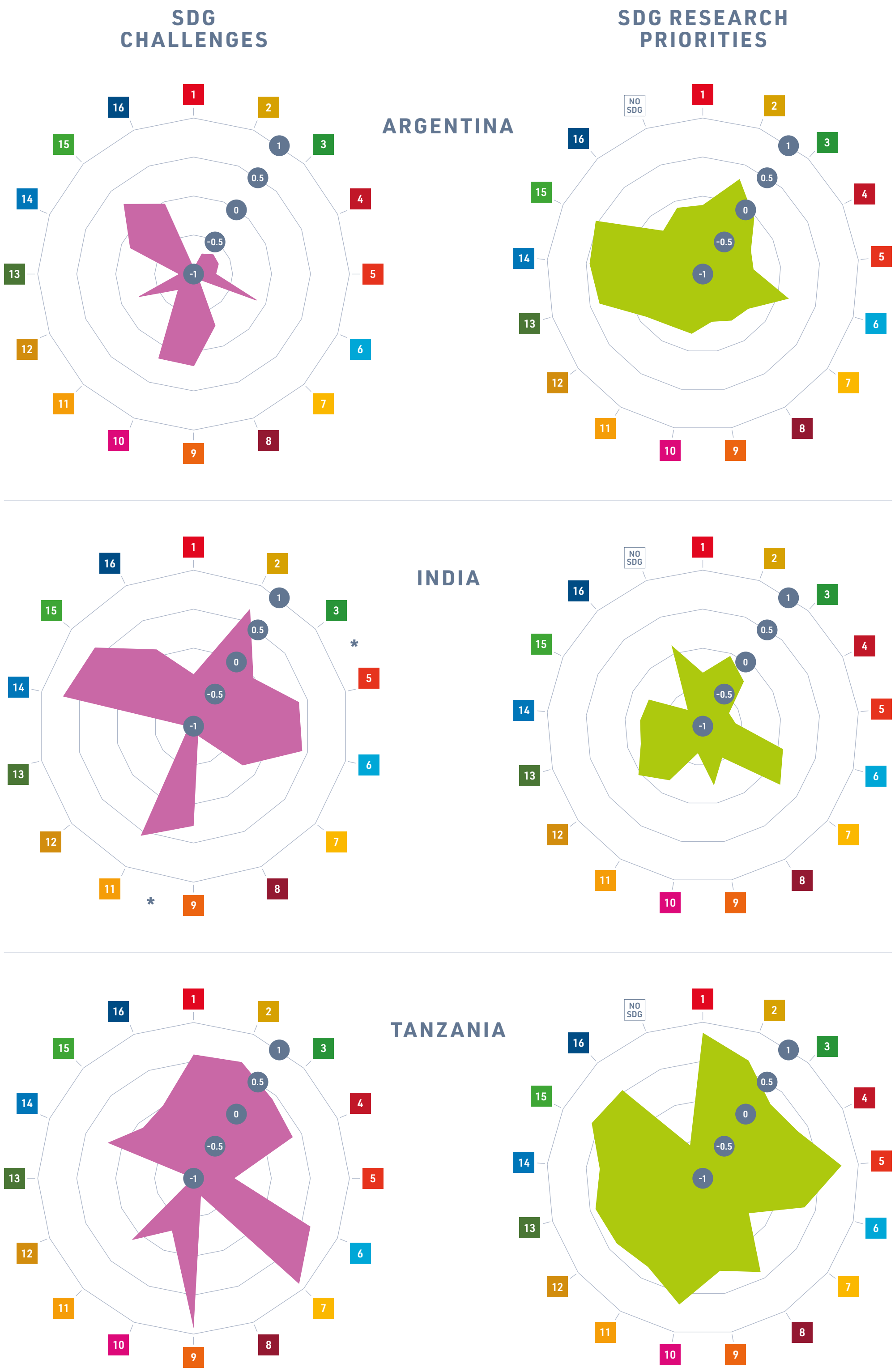
Right hand column:

SDG RESEARCH SPECIALIZATION 2015-2019

Research specialization above 0 indicates that a country is relatively specialized in research related to that SDG. A score below 0 indicates less specialization than the world average.

> KEY: Score range

1	MAJOR challenge HIGH research specialization
0	AVERAGE challenge AVERAGE research specialization
-1	MINOR challenge LOW research specialization



> KEY: Sustainable Development Goals

SDG 1 No poverty	**SDG 2** Zero hunger	**SDG 3** Good health and well-being	**SDG 4** Quality education	**SDG 5** Gender equality	**SDG 6** Clean water and sanitation	**SDG 7** Affordable and clean energy	**SDG 8** Decent work and economic growth
SDG 9 Industry, innovation and infrastructure	**SDG 10** Reducing inequality	**SDG 11** Sustainable cities and communities	**SDG 12** Responsible consumption and production	**SDG 13** Climate action	**SDG 14** Life below water	**SDG 15** Life on land	**SDG 16** Peace, justice, and strong institutions
SDG 17 Partnerships for the Goals							

This pattern of intensive agriculture might, in some cases, lead to unsustainable practices of land use and damage to terrestrial ecosystems. This leads to a trade-off with SDG 15 (Life on Land), which is a particular challenge in this country. Therefore, it is interesting to note the high research specialization in SDG 15, which focuses on issues such as the effects of land use on local biodiversity[7] and the importance of soil science in challenges such as food security, water scarcity, climate change, biodiversity loss and health threats.[8]

The lack of research prioritization in SDG 9 and SDG 10 is worrying given the significant challenge that Argentina faces in relation to these SDGs relative to other countries.[9]

India

In India (an upper-middle income country), alignment is also quite low. The country faces significant challenges in relation to SDG 2, SDG 5, SDG 6, SDG 9, SDG 11, SDG 14 and SDG 15 yet its research priorities relate to SDG 6, SDG 7 and SDG 12.

The specialization in research relating to SDG 6 (Clean water and sanitation) appears to be well aligned with the size of the challenge, given that India still had over 300 million people defecating in the open in 2017.[10] However, the other major challenges – relating to SDG 2, SDG 9, SDG 11, SDG 14 and SDG 15 – receive relatively little research attention.

Tanzania

Tanzania (lower-middle income) faces several challenges that are usually more problematic in low-income countries. These include issues relating to SDG 1, SDG 2, SDG 3, SDG 4, SDG 6, SDG 7 and SDG 9. 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 SDG 7, in which Tanzania is one of the countries furthest away from the SDG frontier.

This analysis can be performed in more detail for each country to better understand research capabilities in relation to SDG challenges.[11] This may help to guide the priorities of national research councils and international research funds.

We also conducted case studies in Argentina and India (see Chapters 8 and 9). Kenya (our third case study country) does not have enough indicators to compute all SDG scores.

Alignment patterns by SDG

Below, we analyse how the alignment between research priorities and major challenges differs for individual SDGs. The alignment patterns for SDGs 2, 4, 6 and 13 are described below and illustrated in Figure 6.3.[12]

We found patterns of alignment for SDG 2 and SDG 6, meaning that countries with significant challenges in these SDG areas are conducting more research related to those SDGs than the average country.

Our methods and approach

SDG-related research

We used the method explained in Chapter 4 to identify research that is related to each SDG. This process involved examining research areas with a high share of publications that contain text related to specific SDGs.

Research priorities

We calculated the research priorities of each country, between 2015 and 2019, by using a comparative specialization index that allows us to measure whether a country's research is more or less specialized in a certain SDG than the world average.[4,5] We used a scale from -1 and 1, where 1 = high specialization, 0 = world average, and -1 = low specialization.

SDG challenges

To analyse each country's SDG-related challenges, we built a unique data set with 80 different indicators covering 16 SDGs (1-16). We calculated the relative distance of each country to the 'frontier' for each indicator, where the frontier represents the performance level of the top 5% countries.

Based on this information, we ran a principal component analysis for each SDG to obtain a single score for the countries and SDGs for which data is available. Countries with a high SDG challenge score are those furthest away from the frontier in that specific SDG, meaning they face a greater challenge in achieving that goal. Countries with a low score are at the frontier in that particular SDG.

For more details about how we created these indicators, please see our working paper: https://www.merit.unu.edu/publications/working-papers/abstract/?id=9407

On the other hand, our analysis shows a misalignment pattern for both SDG 4 and SDG 13, meaning that countries with the biggest challenges relating to these two SDGs are conducting less research on those challenges than the average country.

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 specialization in particular research topics. To address this, we use multiple regression analysis to control for factors such as path dependence (past research specialization) and country research productivity.[13]

When controlling for these factors, we found a robust positive association between the size of an SDG challenge and the development of research priorities in only one SDG: SDG 6 (Clean water and sanitation).

Figure 6.3 / Alignment between SDG challenges and SDG research

The charts show the relationship between SDG challenges (2008-2017) and SDG research priorities (2015-2019) for SDGs 2, 4, 6 and 13.

Countries are shown in different colours based on their income group.

The y-axis represents the research specialization of a country in a certain SDG (> 0 indicates that a country is relatively specialized in research related to that SDG. < 0 indicates less specialization in this area than the world average).

The x-axis represents SDG challenge scores. 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 (see 'Our methods and approach', p75). Each dot indicates a country.

Figures based on Web of Science data (CWTS version) and on the SDG Index data.

> KEY
- High income
- Upper-Middle income
- Lower-Middle income
- Low income

---- Linear regression
----- 95% confidence interval

This means that countries furthest from the frontier in SDG 6 are specialized or becoming specialized in research related to SDG 6. The five countries in which research on SDG 6 represents the largest share of the SDG-related research portfolio are Bolivia, Benin, Ethiopia, Nepal and Zimbabwe. These countries are all low-income or lower-middle income countries which have experienced recent problems related to water governance (for example, the Cochabamba Water war in Bolivia, the 2015–16 El Niño-induced drought in Ethiopia, and lack of access to sanitation and water services in Nepal).

The good match between research priorities and SDG challenges in this case might be related to the occurrence of particular shocks, which have incentivized national and international research funders to solve these issues. However, further research is needed to understand the causes for other alignments and misalignments.

We also found positive pairwise correlations between countries' research priorities and challenges in relation to SDG 1 and SDG 3.[6] These findings indicate that countries with serious challenges in relation to these SDGs are prioritizing related research, which should enable the development of relevant research capabilities. However, these correlations disappeared when we controlled for previous specialization.[6] This implies that the positive correlation between research specialization and SDG challenge for SDGs 1 and 3 is mainly due to historical and long-term research priorities, rather than a response to SDG challenges. These results were expected, since it is well known that lower-income countries have historically specialized in health and agricultural sciences,[14] mainly due to the research funding priorities of aid agencies, philanthropists and other international funders.[15]

Figure 6.4 / Alignments between SDG challenges and SDG research by income group

The graph shows the relation between SDG challenges (2008-2017) and SDG research share (2015-2019) by income group.

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 share of SDG-related research that relates to each SDG by income group. Each colour represents an income group.

> KEY
High income
Upper-Middle income
Lower-Middle income
Low income
Linear regression
95% confidence interval
1–16 SDG number

Source: Own calculation based on Centre for Science and Technology Studies (CWTS) Web of Science version, UN, SDG Index and World Bank data.

> KEY: **Sustainable Development Goals**
SDG 1 No poverty
SDG 2 Zero hunger
SDG 3 Good health and well-being
SDG 4 Quality education
SDG 5 Gender equality
SDG 6 Clean water and sanitation
SDG 7 Affordable and clean energy
SDG 8 Decent work and economic growth
SDG 9 Industry, innovation and infrastructure
SDG 10 Reducing inequality
SDG 11 Sustainable cities and communities
SDG 12 Responsible consumption and production
SDG 13 Climate action
SDG 14 Life below water
SDG 15 Life on land
SDG 16 Peace, justice, and strong institutions
SDG 17 Partnerships for the Goals

For all other SDGs, we found no alignment or a negative alignment. For SDG 12 and SDG 13, the countries with the greatest challenges are high-income countries that have unsustainable consumption and production patterns and contribute the most to climate change. However, these countries do not specialize in research in these areas. The countries that are the most specialized in research related to SDG12 and SDG13 are lower-income countries. This is clearly a severe misalignment since the biggest polluters and CO_2 emitters should be prioritizing research to solve environmental issues.

We also found a negative association for SDG 4 and SDG 15. The countries that prioritize research relating to SDG 4 are also those closest to the frontier for SDG 4. This misalignment might generate further inequalities between different countries' education capabilities, as higher-income countries expand their understanding of best practices while others continue with less efficient methods.[16] In the case of SDG 15, the countries that contribute most to the destruction of biodiversity are not prioritizing SDG 15-related research.

Alignment patterns by income group

Beyond the relative misalignments between national research priorities and challenges, a further source of misalignment exists at the global level due to the vast inequalities in research capabilities and funding across countries (see Figure 6.4).

Low-income countries

While most SDG challenges are worse in lower-income countries, only a small proportion of SDG-related research takes place there. The 29 low-income countries contain 8.2% of the world's population yet contribute to less than 0.3% of SDG-related publications. This negligible involvement of researchers from lower-income countries limits the impact of research in these countries. Research carried out by locals usually brings advantages in terms of ownership of results, trust, sharing of expertise between researchers and policymakers, and increased contextualization of findings. Without this, policymakers and research users must rely on research produced elsewhere, which is likely to be less relevant to their contexts.

The SDG-related research produced by low-income countries relates mostly to SDG 1, SDG 2, SDG 3, SDG 5 , SDG 13 and SDG 15. Together, these SDGs account for more than 50% of all the research carried out in this income group.

Middle-income countries

While the 104 upper-middle and lower-middle income countries produce 37% of all global research, they are responsible for only 32% of SDG-related research. This group is more specialized than the world average in research relating to SDG 6 and SDG 7, and less specialized in SDG 5, SDG 10 and SDG 16. China, India, Brazil and Russia, which contain 75% of the world's population and produce 27% of global research, are included in this group and substantially shape these results.

High-income countries

The 72 high-income countries produce the majority (68%) of all SDG-related research, despite being home to only 16% of the global population. They are relatively specialized in SDG 16, SDG 10, SDG 5 and SDG 4. Their major SDG challenges relate to SDG 8,[18] SDG 12 and SDG 13.

Limitations and pointers for future research

This study has some limitations, related to the uncertainty and ambiguity of our estimates of research priorities[19] and challenges.[20] Our results are thus designed more as a tool to explore potential misalignments between research priorities and SDG-related challenges than as an accurate measure.

Further research is needed on the marginal impact of increasing SDG-related research on the achievement of a particular SDG. This impact may not be the same for all SDGs. For example, more local research in health (SDG 3) may improve a country's health outcomes, but more local research on poverty (SDG 1) may not produce similar progress in poverty reduction. Future studies should look carefully at this issue, as well as considering spillovers between SDGs and the positive and negative interactions between them. These factors may guide research prioritization and enable the building of research capabilities to address the SDGs.

Notes

1. Pavitt, 1998.
2. Salter and Martin, 2001.
3. Balassa, 1965.
4. Ciarli and Ràfols, 2019; Confraria and Wang, 2020.
5. To avoid outliers, we did not include countries with less than 500 publications. This affects mostly low-income countries.
6. We present results for the period 2008-2017, the period for which we could obtain the most data.
7. Newbold et al., 2015.
8. Keesstra et al., 2016.
9. Arza and López, 2021; Cimoli and Katz, 2003.
10. World Health Organization and UNICEF, 2017.
11. Graphs for all countries for which data is available are in the Supplementary Figures, Section 2.
12. Results for all other SDGs are in Appendix 4.
13. See Table A.4.1 in Appendix 4 for a summary of results and further details.
14. Confraria and Godinho, 2015; UNESCO, 2015.
15. Kozma et al., 2018.
16. Nelson, 2011.
17. Kraemer-Mbula et al., 2020.
18. 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 GDP per capita/employed person, rather than the level of per capita income. Since lower income countries' economies grew more during 2008-2017, they score more highly than higher income countries on this indicator.
19. Armitage et al., 2020.
20. Miola and Schiltz, 2019.

> CHAPTER 7

Future STI priorities

Stakeholders' views on how science, technology and innovation can help achieve the SDGs

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OVERVIEW

- This chapter presents the results of a global survey of stakeholders.
- Survey respondents proposed the STI areas and activities that they believe could help to achieve the SDGs by 2030.
- Their responses highlighted a range of STI areas, including policy-oriented, social and grassroots innovations, which are often overlooked in the existing STI system.
- Several STI areas were identified as potentially having a positive influence on the achievement of multiple SDGs.
- The survey results also highlighted that some STI activities may support one particular SDG target at the same time as impeding progress towards another.

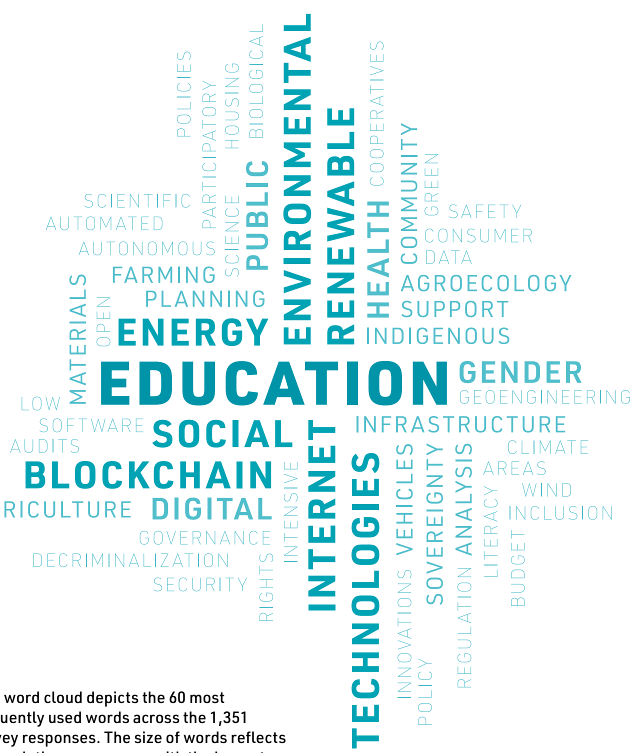
Footnotes for this chapter are on page 86. A full list of references can be found on page 140.

To understand the relationships between science, technology and innovation (STI) and the Sustainable Development Goals (SDGs), we can learn by looking forwards as well as backwards in time. Retrospective observations can locate STI areas that have been privileged or under-supported in the past (see Chapters 4 and 5 for such mappings). However, looking backwards misses emerging ideas and current understandings about how STI can help achieve the SDGs.

By capturing different stakeholders' understandings of STI and the SDGs, we can explore how insights around future STI-SDG influences align with current activities. To this end, we undertook a survey in 2021 to gather a range of perspectives about the types of STI activity needed to achieve the SDGs. This chapter reports on these findings, considering the following key themes:

- **Diversity** of future STI influences
- **Synergies** between multiple SDGs
- **Nature** of influences
- **Degree of consensus** between stakeholders
- **Similarities and differences** between proposed future STI influences and current research and innovation patterns

Figure 7.1 / A snapshot of survey responses about STI for the SDGs



This word cloud depicts the 60 most frequently used words across the 1,351 survey responses. The size of words reflects their relative occurrence, with the largest words being the most common. Word colour intensity decreases with proportional word occurrence in survey responses.

Diversity of proposed STI influences

Future STI influences identified in the STRINGS survey ranged widely (see Figure 7.3) and included:

- propositions for new, or further development of, **research areas**, for example, research on the value of biodiversity
- adoption of **existing technologies** such as carbon capture and storage technology
- system-wide principles to set **directions and values** guiding STI development (such as circular economies)

Respondents highlighted various types of innovation that could influence SDG attainment, including:

- **Market-oriented innovation** (16% of respondents), which aims to improve a product or process. This type of innovation can help to create capabilities, and often involves capturing the resultant revenues, including through the use of patents (see Chapter 5). Innovators range from farmers to multinational corporations and public laboratories.
- **Social innovation** (11% of respondents), which aims to meet social needs not provided for by the market.[1]
- **Adaptive, inclusive and grassroots innovation** (6% of respondents), which uses local inclusion and control to improve technology development and social organization.[2]
- **Policy innovation** (37% of respondents),[3] including changes to the instruments and processes of public administration.

20% of responses focused on the need for values and direction-setting to support the SDGs, for example, by developing circular economy principles to guide STI development.

The results suggest that stakeholders, including scientists, researchers, and technology developers (who between them comprised 69% of survey respondents) believe that traditional scientific and technological developments alone are not sufficient to achieve the SDGs. Authors of academic papers responded to open-ended questions with more diverse STI types than those covered in their collective publications.

The STRINGS survey

The STRINGS survey captured views from more than 1,350 individuals worldwide about the influences of STI on the SDGs. Figure 7.2 summarizes the survey's approach.

How the survey worked

- The survey employed the Delphi technique – a structured method used in policy analysis. It involves relaying ideas and beliefs from other respondents to better inform individual reflection.
- First, respondents were asked to imagine a world in 2030 in which the SDGs have been achieved. They were asked for their views on which STI areas would have been influential in achieving specific SDG targets. To remain open to diverse and plural ideas, the survey imposed no strict constraints on the types of ideas that could be submitted.
- Next, respondents used a five-point scale to indicate whether the proposed STI area would have a positive, neutral or negative influence on SDG achievement.
- From the survey responses, we calculated a consensus score for each proposed STI-SDG relationship.
- Respondents had the option to add comments to contextualize their ratings. They could see the ideas and comments of other survey participants and were free to amend their own contributions at any point.

Who responded to the survey?

- The survey was open to individuals from various backgrounds, with invitations circulated across a wide range of STI and SDG channels and networks
- One-fifth (20%) of respondents contributed to the making of public funding decisions and 8% to private funding decisions
- Most respondents (63%) were male
- Most were in the 35-44 age group (31%), followed by 45-54 (25%), 55-65 (20%), 18-34 (15%) and 65 or older (8%)
- The vast majority (85%) were primarily employed at a university or similar research institution
- Others described their primary employment as the public sector (5%), private sector (3%) or not-for-profit sector (3%)
- 20-30% of participants had expertise in either Europe or North America
- Fewer had expertise in Latin America, South-eastern Asia and Oceania (each between 10-20%), or in North Africa, or Central and Western Asia (less than 5% each)

Further respondent background details are provided in Appendix 5.

An exploratory approach

The combination of 169 SDG targets with thousands of possible STI areas could potentially generate hundreds of thousands of STI-SDG relationships to be appraised. Our study takes an exploratory approach, and concentrates only on the possible relationships proposed by respondents.

Figure 7.2 / A summary of how the survey employed the Delphi technique

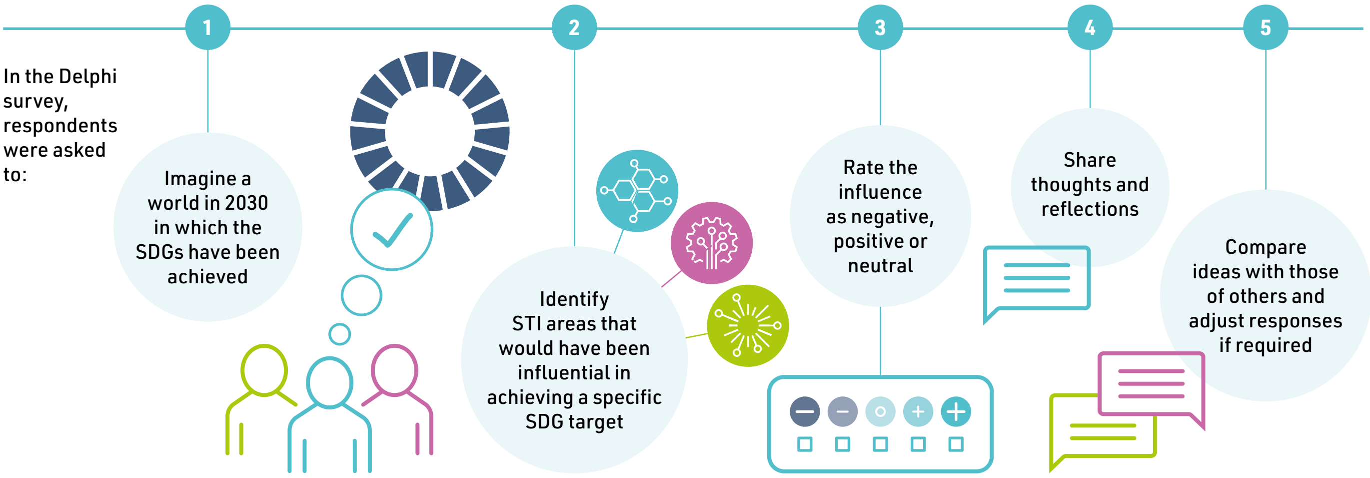


Figure 7.3 / STI priorities identified in the STRINGS survey

Type of STI	% of responses	Examples from survey
Scientific research area	7%	Researching sociotechnical literacy
Existing technology	3%	Solar panels
Market-oriented innovation	16%	Bioelectrochemical systems for charging electric vehicle
Social innovation	11%	Community-based health insurance
Grassroots innovation	6%	Local food supply chains
Policy innovation	37%	Decriminalization of sex work
Values and direction-setting	20%	Plant-based diets

% of responses: 0–9%, 10–19%, 20–29%, 30–39%

The figure shows what percentage of survey responses suggested each type of STI, together with some examples of each type, drawn from the responses. For analysis purposes, we assigned only one STI type for each response. In practice, an activity can fit multiple innovation types.

The misalignment between respondents' perspectives and their own research focus can be explained partially by the constraints of research support and incentive systems that favour publication in specific technical domains. These factors tend to result in research that is less interdisciplinary,[4] less likely to be grounded in a local context,[5] and less risky.[6]

Only 19% of survey responses could be categorized using International Patent Classification codes (most of these were categorized as 'market-oriented' innovations). This relatively low percentage indicates that most STI areas proposed by survey respondents are different from those mapped using typical patent-focused methodologies (see Chapter 5).

Synergies and trade-offs

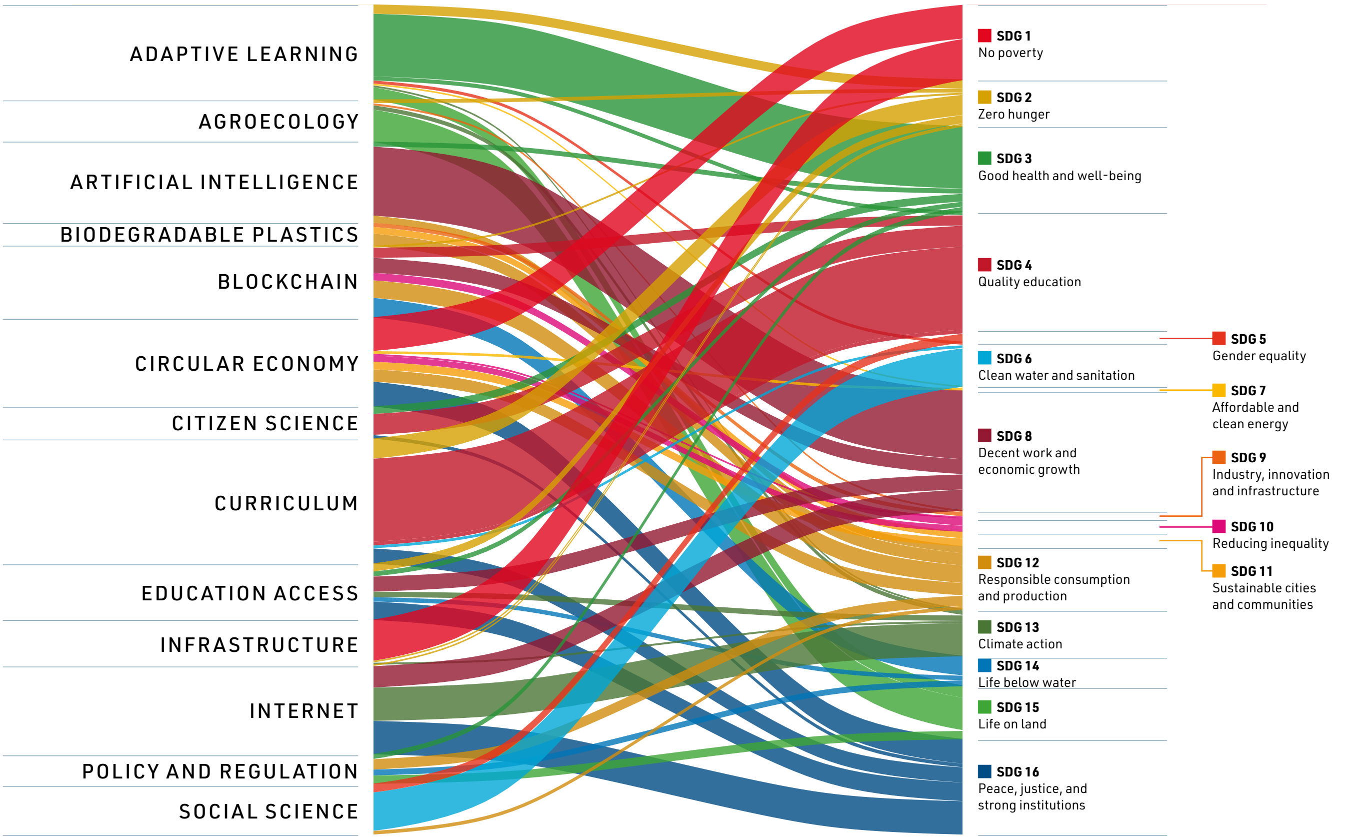
Where one area of STI supports the achievement of multiple SDG targets, a **synergy** exists across these targets.[7] However, links between the SDGs are not always positive. For example, a development in one STI area may support one SDG target, while inhibiting progress towards another. Such 'negative synergies' are also known as **trade-offs**.[8] Figure 7.4 illustrates the positive and negative influences identified in the STRINGS survey for one example STI area – blockchain technology.

The survey identified 13 STI areas as synergistic, linking to three or more SDGs[9] (see Figure 7.5). These include areas of research, such as social science; market-oriented innovations, such as biodegradable plastics; existing technologies, such as the internet; and policy innovations, such as enhanced monitoring and evaluation.

Figure 7.4 / Synergies and trade-offs for one STI area

Example of an STI area	SDG targets	Survey descriptions of STI influence on SDG achievement
BLOCKCHAIN TECHNOLOGY	**SDG 5.1** End of discrimination against women and girls	INFLUENCE: NEGATIVE Blockchain cryptocurrencies are used as payments for sexual abuse of women and girls, bypassing regulated banks
	SDG 8.10 Expand access to financial services	INFLUENCE: POSITIVE Blockchain enables payment systems for people excluded from mainstream banking services
	SDG 12.2 Sustainable management of natural resources	INFLUENCE: NEGATIVE Blockchain cryptocurrencies can be more energy-intensive than the resource management benefits they support
	SDG 12.5 Waste	INFLUENCE: POSITIVE Transparent blockchain ledgers improve accuracy in tracing feedstock provenance and quality for plastics recycling
	SDG 14.1 Marine pollution	INFLUENCE: POSITIVE Tamper-proof ledgers of pollution levels encourage polluter responsibility

Figure 7.5 / STI synergies across the SDGs



The figure shows the links to various SDGs for the STI areas that are linked to more than three SDGs. Line colours reflect a specific STI area.
Line thickness is proportional to the number of survey responses that identified a specific STI-SDG link.

It is unsurprising that respondents identified more than one potential use for several STI areas. Technological innovation arises from this type of flexibility – for example, repurposing or adapting existing components into new and very different applications[10] or contexts.[11]

Many of the synergistic STI areas identified by the survey relate to general processes and systems that can strengthen other areas of STI, and improve the capacity of people, organizations and society to achieve the SDGs.[12] For example, artificial intelligence algorithms applied to publicly accessible data about household waste levels and stored on ***blockchain*** ledgers can be used to implement ***adaptive learning*** to identify missed waste reuse opportunities for local businesses. This information can be used to learn about existing policy or regulation barriers to domestic waste reuse, and monitor the impact of their adjustment.

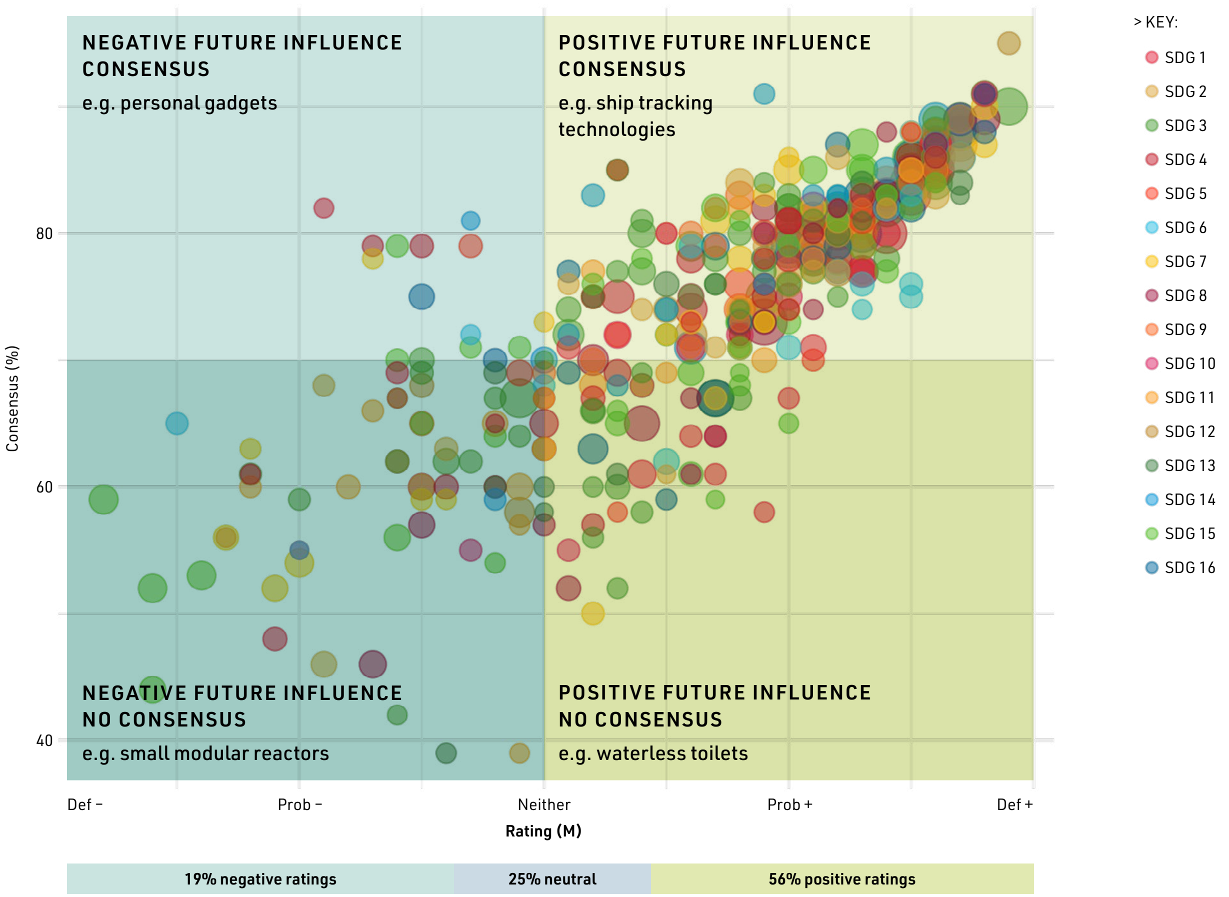
While the role of STI in developing mutually beneficial synergies for local and global capacity-building is recognized in global SDG action, STI capacity-building in low-income countries is almost absent from published research and inventions (see Chapters 4 and 5).[13]

Nature of influence and degree of consensus

Survey respondents rated each of their proposed STI areas according to the expected **future nature of influence** (positive or negative) and the **likelihood** (probable or definite) of its impacting on the SDGs. We also measured the **degree of consensus** (a measurement of agreement between stakeholders).[14,15]

The permutations of the nature of influence and consensus form a framework to explore future significance.[16] We can identify where there is strong consensus that particular STIs will have a positive future influence on SDG attainment, and also those STI-SDG relationships for which there is much less agreement. Figure 7.6 uses four examples from the survey responses to illustrate areas with and without consensus about positive or negative future STI influences on SDG attainment.

Figure 7.6 / Survey perspectives on the future influence of STI on SDG attainment



Rating (M) is a measure of likely STI influence on SDG attainment using a scale from definitely negative, to probably negative, to a neutral midpoint, to probably positive, to definitely positive. Consensus (%) is a measure of relative agreement across survey respondents.[18]

Every survey response is represented by a dot. Responses are distributed according to the degree of consensus on likely future direction. Most survey responses described STI areas with **positive** future influence on SDG achievement and are therefore on the right-hand side of the chart.

Most responses identified a positive or neutral STI influence on target SDGs:

- 56% of the identified STI-SDG relationships were perceived to have a positive and supportive influence on SDG attainment
- 25% were rated neither positive nor negative
- 19% were described as having a negative future influence

The higher proportion of positive results may be due to the 'goal framing' effect, whereby an issue is framed positively within a question.[17] The STRINGS survey asked respondents to identify STI influences in the context of the successful attainment of 2030 SDGs, which could have led to more positive responses. This effect should be accounted for in future analyses exploring STI-SDG relationships.

In some cases, survey respondents had highly polarized perspectives about an STI-SDG relationship. For example, the use of blockchain technology was rated by some responses as a definite positive influence towards meeting Target 11.6: 'reduce adverse environmental impact of cities, by paying special attention to air quality and municipal and other waste management'. An equal number of responses rated its influence as definitively negative towards SDG achievement. This results in an average 'neither' rating along the centre line of Figure 7.6.

We found the greatest consensus about the positive scoring STIs. This phenomenon – known as the desirability effect (where there is greater consensus about the likelihood of good things in the future than about bad things) is often encountered in similar studies.[19]

Table 7.1 / Highest- and lowest-rated STI types across all SDG targets

HIGHEST RATED

STI influences rated by at least 10 respondents were ranked by highest mean rating and highest consensus to identify the ten highest rated STI areas

SDG target	STI	Type	Mean rating	Consensus %	Responses %
SDG 12.3 Food waste	Education and marketing to change consumer behaviour	Social innovation	4.94	95	16
SDG 3.2 Newborn and child death	Public health	Policy innovation	4.88	90	196
SDG 7.1 Energy access	Renewable energy	Market-oriented innovation	4.85	91	227
SDG 10.2 and 10.3 Inclusivity	Social justice	Values and direction-setting	4.85	91	33
SDG 15.8 Invasive species	Regulations and controls on invasive species	Policy innovation	4.81	91	42
SDG 7.2 Renewable energy	Solar energy	Market-oriented innovation	4.78	87	32
SDG 16.7 Decision-making	Protection of voter rights	Values and direction-setting	4.76	88	17
SDG 11.3 Urbanization	Affordable housing	Policy innovation	4.76	91	21
SDG 8.7 and 8.8 Labour	Education	Social innovation	4.75	89	92
SDG 7.3 Energy efficiency	Building energy efficiency	Market-oriented innovation	4.75	90	40

LOWEST RATED

STI influences rated by at least 10 respondents were ranked by the lowest mean rating and a consensus of more than 50% to identify the lowest 10 rated STI areas

SDG target	STI	Type	Mean rating	Consensus %	Responses %
SDG 15.5 Biodiversity	Conversion of natural areas for agriculture and livestock	Values and direction-setting	1.25	60	69
SDG 2.1 Food access	Genetically modified crops	Existing technology	1.50	65	12
SDG 15.3 Desertification	Heavy agricultural mechanization	Existing technology	1.65	54	65
SDG 7.1 Energy access	Natural gas exploitation	Market-oriented innovation	1.68	55	31
SDG 3.2 Newborn and child death	Population control	Values and direction-setting	1.79	61	14
SDG 11.1 Housing	Abolish private property rights	Values and direction-setting	1.83	61	12
SDG 7.1 Energy access	Small modular reactors	Market-oriented innovation	1.87	52	38
SDG 7.3 Energy efficiency	Next-generation nuclear	Market-oriented innovation	1.95	53	63
SDG 3.4: Non-communicable diseases	Augmented reality	Market-oriented innovation	2.00	59	13
SDG 2.1: Food access	Organic agriculture	Market-oriented innovation	2.09	66	11

Rating of future STI-SDG influences

The STI areas with a high consensus about their positive future influence towards SDG achievement (see upper-right-quadrant in Figure 7.7) include a diversity of STI types. On average, social innovations were the highest-scoring influences, and market-oriented innovations were the lowest.

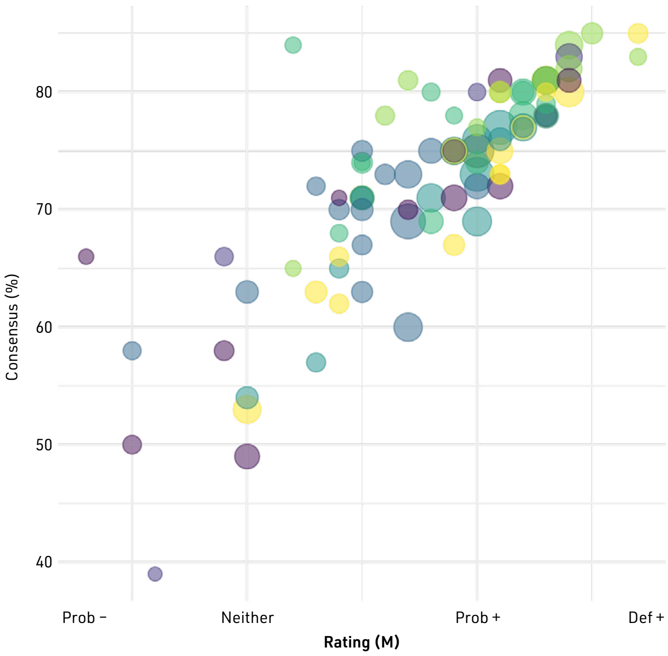
The ten highest-scoring STI influences identified in the survey (see Table 7.1) include only one market-oriented innovation: solar energy for renewable energy. This identification of an energy technology aligns with the data on patent activities: SDG7 (Affordable and clean energy) is the second most common area for SDG-related patent activity, following SDG3 (Good health and well-being).

However, the ratings of future influence provided by our survey participants contrast with the direction of current research and innovation, as mapped in earlier chapters of this report. For example, while the survey responses tend to focus on issues such as social justice, voter rights and affordable housing, we found that research publications relating to societal issues of inequality, education and conflict attract less funding and are more disconnected from research on other SDGs (see Chapter 4).

Several of the STI areas with the lowest mean ratings (see Table 7.1) are existing technology and market-oriented innovations: genetically modified crops, heavy agricultural mechanization, small modules, next-generation nuclear, and augmented reality. However, Chapter 5 shows that there has been recent innovative activity in these areas.

Section 3 (Conclusions and recommendations) of this report addresses ways in which these clear misalignments between current STI activity and the perspectives of expert participants in the STRINGS survey can be addressed.

Figure 7.7 / Consensus-rating plots for STI types across SDGs 1-16



Rating (M) is a measure of likely STI influence on SDG attainment using a scale from definitely negative, to probably negative, to a neutral midpoint, to probably positive, to definitely positive. Consensus (%) is a measure of relative agreement across survey respondents.

Each dot denotes a specific STI type-SDG relationship proposed by STRINGS survey respondents for SDGs 1-16. Each colour represents the type of STI, as elaborated in 'Diversity of proposed STI influences' on page 80. The size of the circle indicates the relative number of responses that rated that STI-SDG relationship.

> KEY:

- Existing technology
- Grassroots innovation
- Market-oriented innovation
- Policy innovation
- Scientific research area
- Social innovation
- Values and direction-setting

Notes

1. OECD/Eurostat, 2018.
2. Kaplinsky, R. et al., 2009.
3. OECD/Eurostat, 2018.
4. Rhoten, D. and A. Parker, 2004.
5. Chavarro, D. et al., 2014.
6. Gewin, V., 2012.
7. Pradhan, P. et al., 2017.
8. Ibid
9. Section 5.3 in Appendix 5 summarizes the identified synergies for STI areas with identified influence on the achievement of three or more SDGs.
10. Arthur, W. Brian, 2009.
11. Kaplinsky, R., 2011.
12. UNDP, 2009.
13. UN-IATT, 2011.
14. Diamond, I. R., et al., 2014.
15. Section 5.4, Apeendix 5 summarizes the STI-SDG relationships with highest consensus and rating, according to respondents' region, expertise, role, disciplinary background, SDG expertise and age.
16. Ramirez, R. and Wilkinson, A., 2014.
17. Cheng, F.-F. and Wu, C.-S., 2010.
18. Two factors were taken into consideration for the measurement of 'consensus': the 'variation' across ratings for a given STI influence on an SDG target (calculated by dividing the standard deviation by the mean of these ratings given by survey responses); and a 'stability' weighted factor, reflecting whether respondents adjusted their initial ratings when they viewed others' scores and reflections.
19. Ecken, P et al., 2011.

> CHAPTER 8

Alternative STI pathways

Three case studies of local STI pathways in Argentina, India and Kenya

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OVERVIEW

This chapter introduces our three case studies, which map alternative STI pathways in three different locations.

The case studies focus on the following challenges, which relate to a range of Sustainable Development Goals (SDGs) as follows:

- Seed development in Odisha, India, to address climate stresses and other problems facing rice cultivation (relevant SDGs 1, 2, 3, 8, 10, 13 and 15)
- Tackling Chagas disease in Argentina (SDGs 1, 3, 4, 5, 9, 11, 15 and 16)
- Addressing conflicts around overfishing in the Lake Victoria region of Kenya (SDGs 1, 2, 3, 5, 14 and 16)

Each case study was selected for its relevance to multiple SDGs.

Footnotes for this chapter are on page 96. A full list of references can be found on page 140.

How we identified the pathways

We used a variety of methods to map the diverse STI pathways in our three cases.

In India

We started with a detailed review of journal papers and grey literature, including annual reports of relevant organizations and project completion reports. We then conducted semi-structured interviews with key stakeholders.

In Argentina

We reviewed secondary sources on Chagas and conducted interviews with 13 representatives of five research projects and with seven key informants from policy and non-governmental organizations.

In Kenya

Building on an extensive literature review and a scoping workshop to map the issues and actors, we conducted semi-structured telephone interviews, administered an email questionnaire among key stakeholders, and held focus group discussions.

What are STI pathways?

Science, technology and innovation (STI) activities can develop in multiple directions. To address this multiplicity, we use the concept of STI pathways.[1] In each area of activity, a diverse range of STI pathways is possible.[2] For example, in transport, one STI pathway focuses on developing vehicles, road infrastructure and regulations for speed and pollution control. An alternative pathway might be structured around infrastructure for cycling and walking, planning cities and towns to minimize commuting distances, and policies that prioritize health and ecology over economic growth.

The pathways concept highlights how individual STIs are always developed within wider social, environmental, institutional and political contexts. Each pathway comprises specific STIs, the actors who develop them, and the institutions that promote and regulate this development. Rather than being simply an output, a pathway is a process that can evolve in nonlinear directions and is simultaneously social, political, ecological and techno-scientific.

Generally, just one or two STI pathways dominate in any area of activity.[4] For example, in agriculture, the internationally dominant pathway focuses on modern STIs such as hybrid and genetically modified seeds, precision agriculture based on artificial intelligence and data analytics, and modern pesticides and synthetic fertilizers.[5] More marginalized are the pathways based on diverse agroecological techniques, non-pesticidal management, rainwater harvesting, and farm-saving of seed varieties that are adapted to local conditions.[6] By directing attention to pathways that are marginalized yet equally effective in addressing sustainability goals (see Chapter 9), the pathways approach can open up new directions of sustainable development,[7] thus reducing the dominance of incumbent pathways.[8]

For each case study (India, Argentina, Kenya), we consider how diverse pathways have evolved to tackle sustainability challenges. Any pathway can be understood in plural ways, and it is impossible to produce a singular self-evident mapping of any pathway.[9] We highlight this plurality of perspectives in Chapter 9. Space limitations mean that our descriptions of the pathways below are necessarily incomplete.

CASE STUDIES

Diverse pathways for rice seeds in India

Farmers have been cultivating rice in India for at least 7,000 years, growing a vast range of varieties to suit the country's diverse climates and ecosystems. However, this biodiversity has declined rapidly in the last six decades since the country's Green Revolution (GR). The GR saw philanthropists, international agricultural research organizations, development aid agencies, Indian state bodies and private corporations start to promote agricultural modernization based on toxic pesticides, synthetic fertilizers, and 'high-yielding' and hybrid varieties of seeds.[10] In the 1950s, before the GR, more than 100,000 varieties of rice were grown in India. This figure is now estimated to be just 7,000. By the 1990s, the bulk of India's rice production was focused on less than 50 modern varieties.

Below, we describe one STI pathway based on breeding hybrid seeds associated with agricultural modernization, and another pathway that focuses on conserving heirloom varieties of seeds.

The seed breeding pathway

In an attempt to tackle the stresses of droughts, floods and cyclones, agricultural scientists are breeding 'improved' rice seeds that are designed to be high-yielding and stress tolerant. In the state of Odisha, the breeders are based largely at the Government's Indian Council of Agricultural Research (ICAR), the National Rice Research Institute (NRRI) and at Odisha University of Agriculture and Technology (OUAT). Together, the NRRI and OUAT have released about 200 varieties of seeds for Odisha's four main rice ecosystems – irrigated, rainfed-low-land, rainfed-upland and flood-prone – which each face several unique stresses. The actors involved in the breeding pathway and their different roles are listed in Table 8.1.

The seed breeding pathway is dominated by government institutions, with private firms playing a crucial role in the sale of seeds. The role of farmers in this pathway is limited. They are primarily buyers of the seeds, although many cultivate their own farm-saved seeds and exchange seeds with other farmers.

The seed conservation pathway

We identified a second pathway, which promotes seeds grown and saved primarily by Odisha's Adivasi communities, largely through in-situ conservation of 'heritage' or 'heirloom' varieties on farms. These seeds are freely shared, often facilitated by individual seed champions, seed conservationist groups, local civil society organizations and community seed banks (see Table 8.2).

Adivasi people often prefer heirloom seeds for their taste and aroma. These varieties are also used in religious rituals and festivals, and the straw from the rice crops may be used as fodder and to thatch roofs. Heirloom varieties are often

Table 8.1 / Main actors and their roles in Odisha's seed breeding pathway

Actors	Roles
Indian Council of Agricultural Research (ICAR)	• Administrative and financial support • Supports the All India Coordinated Rice Improvement Programme (AICRIP) to lead trials
ICAR National Rice Research Institute (NRRI), Odisha	• Researches, develops and releases high-yielding varieties (HYVs) • Collaborates with local Krishi Vigyan Kendras (see below), NGOs and farmer-producer companies to demonstrate the potential of new varieties • Collects rice germplasm
Odisha University of Agriculture and Technology (OUAT)	• Researches, develops and releases HYVs • Coordinates a local AICRIP centre to evaluate new varieties and maintain germplasm • Manages a regional research and technology transfer station
Krishi Vigyan Kendras (district centres set up by ICAR to provide farm support)	• Organizes on-farm testing of new varieties plus demonstrations and training to promote new HYVs
Odisha Department of Agriculture & Farmers' Empowerment	• Promotes HYVs and hybrid varieties recommended by OUAT • Implements government programmes to promote new varieties, such as providing subsidies and organizing demonstrations
Odisha state seed Corporation (OSSC)	• Produces certified seeds through programmes involving growers • Sells certified seeds through government shops and private seed sellers
Odisha State Agro-Industries Corporation	• Public sector marketing channel for seeds
National Seeds Corporation	• Supply of rice seeds beyond Odisha, particularly for programmes such as the National Food Security Mission (NFSM) and Bringing Green Revolution to Eastern India
International Rice Research Institute (IRRI), the Philippines	• Provides access to global elite rice germplasm • Trains scientists in modern rice breeding methods
IRRI Odisha State Office	• Promotes 'climate-resilient' varieties of rice in collaboration with OSSC, Department of Agriculture and NGOs, using field-level evaluation, cluster demonstrations, training and other capacity development
State Seed Testing Laboratory (SSTL), Government of Odisha	• Tests seed samples for quality • Facilitates validation and certification of local rice varieties collected from different parts of Odisha • Trains seed growers and traders in seed testing technology
Seed growers (about 5,000 registered with OSSC) and seed producer groups	• Grow seeds that can be submitted for validation, certification and labelling (facilitated by SSTL)
Private sector seed companies	• Supply roughly 5,000 metric tonnes of rice seeds every year

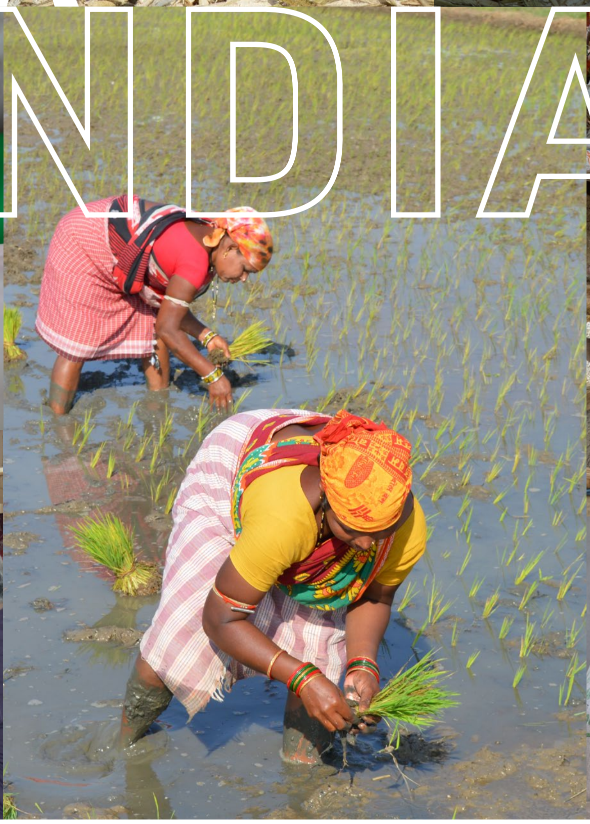
CASE STUDY

We studied two contrasting STI pathways relating to the breeding of rice seeds in India. The first involves hybrid seeds, which have been designed by agricultural scientists to be high-yielding and to withstand the stresses of droughts, floods and cyclones. The second pathway focuses on conserving heirloom varieties of seeds. These seeds are freely shared, often facilitated by community groups.

SDGs related to this study:

1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
8 DECENT WORK AND ECONOMIC GROWTH
10 REDUCED INEQUALITIES
13 CLIMATE ACTION
15 LIFE ON LAND

ODISHA INDIA



All photography courtesy of CRISP.

Table 8.2 / Main actors and their roles in Odisha's seed conservation pathway

Actors	Roles
Civil society organizations including Pragati, MS Swaminathan Research Foundation, and Living Farms	• Document hundreds of farmer-led (heritage or heirloom) rice varieties and promote their cultivation as well as the selection of seeds for saving • Organize seed exchanges and community-based seed banks • Provide training to farmers on seed quality and storage
Individual seed champions	• Revive critically endangered varieties, often through organic cultivation on own land • Collect, cultivate, conserve and share hundreds of heirloom varieties, sometimes in collaboration with CSOs
Seed growing farmers (mainly Adivasi) and their groups	• Conserve and grow heritage or heirloom varieties of rice • Share them freely with other farmers
State Seed Testing Laboratory (SSTL), Government of Odisha	• Collects heirloom varieties from farmers and prepares them for validation • Evaluates the quality characteristics of heirloom varieties collected from farmers

claimed to be less vulnerable to pests and diseases. They can withstand drought and water logging, and the Adivasi farmers who grow them generally use very few, if any, synthetic fertilizers and pesticides.

Unlike the breeding pathway, the conservation pathway has received very little support or investment from public institutions or private businesses, although some civil society organizations have carried out seed conservation work as part of larger government programmes such as the Women Farmers Development Programme.

Due to the public support and investment it receives, the breeding pathway dominates rice seed production in Odisha. Seeds developed in this way are often sold by private firms and are widely adopted by large, medium and small farmers. In contrast, as noted above, heritage and heirloom varieties saved on-farm are used largely by smaller Adivasi farmers.

Pathways of research into Chagas in Argentina

Argentina has one of the world's highest rates of Chagas or American trypanosomiasis – a disease associated with a parasite hosted by the triatomine insect, also known as the kissing bug. The spread of Chagas is a complex socio-ecological issue,[13] a function of ecological as well as socioeconomic conditions, including industrial and agricultural production, housing, and unequal access to quality health care and education.

We studied five research projects, spanning the social and natural sciences, that are aiming to tackle Chagas in Argentina. Among these projects, we identified two main pathways: conventional science (CS) and open science (OS). These descriptions are based on the practices within projects, rather than projects as a whole. Social, environmental, institutional and political contexts are often crucial in determining whether a particular research project follows the OS or CS pathway.

Conventional science pathway

CS is driven by competition, not just in corporate science but also across universities and public research institutions.[14] Science and technology ministries and organizations compete for resources with other sectors, and scientists themselves compete in many ways: for example, to attract research funding and advance their careers through patents, publications, consultancies and membership of panels.

In CS, most output is published in academic journals behind paywalls or locked behind intellectual property rights. It promotes a particular model of science's relationship with wider society, in which impact is sought through the 'transfer' of techno-scientific outputs. The outputs are designed to be further developed and used by stakeholders in markets and civil society. This linear approach has been critiqued since the 1980s,[15] and several alternative models of knowledge production have been promoted. Arguably the most prominent non-linear model is 'Mode 2',[16] in which scientific research is observed to be produced 'in the context of application'.[17]

The studied projects include an Argentinian public-private partnership to develop a Chagas diagnostic kit. This project uses CS practices. Access to data about the analytical and clinical evaluations is restricted, and the kit will eventually be sold for profit by the private firm.

In another project that uses CS, Chagas advocacy NGOs worked in collaboration with a data science firm to develop a risk map using mobile phone data to identify the Argentinian regions that are likely to have the highest incidences of Chagas and sanitary vulnerability. In line with CS practices, researchers alone made the methodological decisions about what constitutes 'risk' and 'vulnerability' and how to measure them.

CASE STUDY

Argentina has one of the world's highest rates of the disease Chagas. We identified two main pathways for tackling the disease. The first, conventional science, includes studies that are published in academic journals or locked behind intellectual property rights. The second pathway involves open science projects – such as open research databases and citizen science – which provide open access to research outputs and involve collaboration beyond academia.

ARGENTINA

SDGs related to this study:

Images taken from a video on Chagas Research, produced by CONICET Nordeste, Argentina.
https://www.conicet.gov.ar/con-micro-y-nanotecnologia-desarrollan-nuevas-alternativas-para-tratar-el-chagas/

Open science pathway

We characterize OS as using two sets of practices,[18] as follows:

a) opening up *access* to intermediate and final outputs of research, including data, software codes and research papers
b) *collaboration* with others in intradisciplinary, interdisciplinary or transdisciplinary ways, including citizen science and open-source drug development.

All five of the projects we studied involved some collaboration, often going beyond universities to involve transdisciplinary knowledge production with a business or policymaking organization. However, transdisciplinary research that involved patients with Chagas disease was rare.

In just one of the projects that addressed Chagas disease as a multidimensional socioeconomic and ecological issue, researchers worked closely with affected communities and collaborated with schools and universities to develop educational

Table 8.3 / Open science practices across five projects in Argentina

PROJECTS	DIAGNOSTIC KIT	ONLINE DATABASE for tropical disease pathogens	COMMUNITY-BASED EDUCATION about Chagas	APP to show the geographical distribution of the kissing bug	RISK MAP of the Chagas epidemic
COLLABORATION					
What aspects involved collaboration?	Much of the research process	Defining the research agenda and initial phase of the project	Entire research process, including project development and engagement	Geotagged data on the distribution of the kissing bug	Data analysis: combining mobile phone data with socioeconomic information
How was this achieved?	Team formed through a funding scheme to promote public-private initiatives	Collaboration promoted by funding bodies	Through the multidisciplinary team's commitment to openly welcoming new members	Mobile phone app	Philanthropic funding initiative and networking
Who were the collaborators?	Research centres and a private firm	Academic community and the private sector	Academic and civil society organizations, artists, teachers, students, community members	Research centres, county governments and wider community	Academia, NGOs and the private sector
ACCESS					
What aspects were made accessible?	None	Open-access database	Reports, books and leaflets; community workshops; public engagement activities	Access to databases on the geographical distribution of kissing bugs across Argentina	Final outputs; municipal level data on Chagas prevalence and quality of sanitary services
How was this achieved?	n/a	Online platform	Website; activities in hospitals, libraries, museums and schools	Open-source app and website	Intermediate data accessible online
Who were the collaborators?	n/a	Researchers in public and private sector	Academic and civil society organizations, artists, teachers, students and community members	General community, academia and policy	Policymakers and academic researchers

programmes. The project also involved exchanges with a social movement, a museum and groups of artists. Outputs included audio-visual materials, books and information brochures – all openly accessible and written in non-specialist language. This project included researchers from diverse backgrounds (including molecular biology, entomology and social science).

Open-access practices differed across the projects (see Table 8.3). One project involved an open-access database of genome sequences and protein structures of tropical disease pathogens, along with information on targets for drugs. The intended users are researchers in drug discovery. While the platform is available to all, the technical nature of the information means that only a small group of researchers are able to access it.

In the risk map project discussed above, the two final papers were made openly available, along with indicators developed in the project. However, access to the mobile phone data used to develop the indicators was restricted due to a contractual embargo involving a firm. This is an example of how the wider context can constrain OS and promote conventional (closed) research practices.

STI pathways to address fishing conflicts in Kenya

Lake Victoria (LV) connects Kenya, Uganda and Tanzania, covering an area of 69,000 km². It has historically been home to more than 500 endemic fish species,[19] many of which, including the Victoria tilapia, are now considered endangered.

The LV region accounts for about 75% of Kenya's fish production.[20] Between 1954 and 1963, the British colonial Government introduced the Nile perch to LV, claiming it would reduce fishing pressure on endemic species, including the Victoria tilapia.[21] However, the Nile perch turned out to be a damaging predator. By 1998, about 100 species of fish endemic to LV entered the International Union for Conservation of Nature's Red Book of endangered species.[22] Alongside the introduction of the Nile perch, causes of declining fish populations include changes in catchment processes, and increased fishing intensity, largely due to industrial fishing.[23] The combined effect is conflict around fishing in the LV region.

Conflicts exist between fishing communities in Kenya, between Kenyan counties, and between Kenya and other countries in the LV Basin. They involve disputes over fishing zones and quotas, often leading to violence, theft and loss of human life.[24] The Government of Kenya believes that illegal, unregulated, and unreported fishing (IUUF) and overfishing are among the main causes of conflicts in Kenya's LV Basin, and is attempting to address these issues through three main STI pathways, outlined below.

Monitoring, control and surveillance pathway

The Kenyan Government has worked with the Kenya Coast Guard Service, Kenya Fisheries Service, the Kenya Police Service, and beach management units (BMUs) to intensify monitoring, control and surveillance (MCS) systems.[25]

BMUs in each area include representatives of fishers, the Coast Guard and Fisheries Service. They use a voluntary, community-based, consultative approach to monitor and control IUUF and overfishing. The BMUs share information about changes in fish stocks and help set voluntary fishing restrictions during particular seasons in certain zones of the lake. They use social media to promote awareness among fishers and the local community about the impact of IUUF and overfishing on food security and local economies.

In addition, there is state-led policing of IUUF and overfishing, with judicial institutions settling disputes and issuing penalties. Policed MCS relies heavily on smartphone technologies but, according to our interviewees, this is hampered by a lack of access to smartphones and poor internet connectivity. The use of geographical positioning systems and satellite technologies is similarly limited.

Interviewees told us that MCS tends to be hampered by state agencies' lack of enforcement, particularly among the powerful industrial fishing sector (see Chapter 9).

Cage aquaculture pathway

Local and national governments are also promoting alternative sources of fishery incomes. Cage fishing has become increasingly popular on the Kenyan side of the LV basin since the mid-2000s, and was supported by an economic stimulus programme in 2009. By 2019, there were 3,696 cages across the Kenyan LV region.[26]

In our mapping, we focused on the sub-county of Bunyala, home to around 160 active cage fishers. We conducted site visits and interviews between August 2020 and February 2021 and identified four different groups of cage fishers:

(a) registered **private companies**, often also involved in constructing cages, culturing young fish and producing fish feed
(b) a few powerful **individuals** politically connected to the Busia County government
(c) three **women's cooperative associations** linked to the Catholic church
(d) **small-scale farmers**, transitioning from artisanal fishing in the lake

As in the wider LV region, a majority of the cages in Bunyala were owned by groups (a) and (b). The small-scale cage fishers were financially supported by at least three Savings and Credit Cooperative Organizations, and a micro-finance institution – the Kenya Women Finance Trust – supported the women's groups' investments in cage fishing.

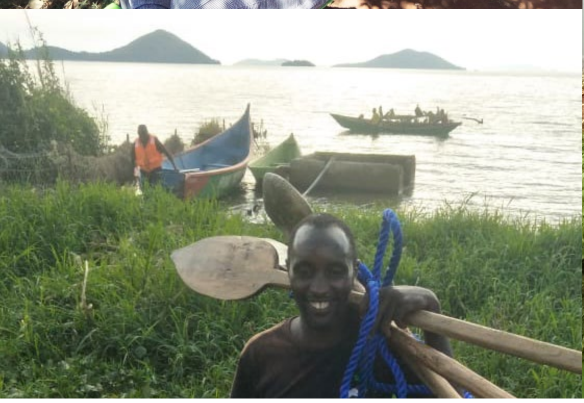
CASE STUDY

LAKE VICTORIA REGION
KENYA

Conflicts over fishing zones and quotas in the Lake Victoria Basin often lead to violence, theft and loss of human life. The Government of Kenya believes that illegal, unregulated, and unreported fishing and overfishing are among the main causes of conflicts and is attempting to address the problems through three main STI pathways: monitoring, control and surveillance; cage fishing; and pond fish farms.

SDGs related to this study:

1 No poverty; 2 Zero hunger; 3 Good health and well-being; 5 Gender equality; 14 Life below water; 16 Peace, justice and strong institutions



Photography: Fred Juma and Paul N Kombo

National government agencies and local government departments also play a part in this pathway – designing regulations, issuing licences and conducting environmental impact assessments (EIAs) for cage fishing. Meanwhile, public universities provide technical support for managing fish diseases, genetics and breeding, and addressing the environmental consequences of cage farming.

Some local and international NGOs also support cage fish production in the area, training fish farmers in sustainable practices and working with policymakers to strengthen EIAs and regulatory governance.

Pond fish farming pathway

Pond fish farms are increasingly being developed and managed by private companies, small-scale farmers, and women's groups. Women are supported by national and local governments through credit and training in pond fishing, and are estimated to own about half the fish ponds in Bunyala. Other actors in this pathway include international donors, funders, university researchers and NGOs.

The NGOs Farm Africa, World Neighbours, Smart Fish, ASRECA, IUCN and ActionAid all work with farmers, government authorities, communities and local researchers to promote sustainable pond fishing. They provide training, share knowledge, offer technical advice and provide access to equipment. Some NGOs also lobby for public policies to ensure that small-scale fishers are not excluded or marginalized.

Many farmers use their own homesteads for pond fishing while some make use of idle land around the lake shores. Ponds constructed on homesteads by small-scale farmers can be as small as 500-600 m^2, while those used by large-scale farmers can be as large as 80,000 m^2.

Our respondents reported a lack of policy and legal frameworks to regulate pond fish farming. Another issue relates to land tenure, which one respondent from an international NGO described as "a main policy impediment to advancing sustainable on-land fish farming". Many households of fishers, especially women, do not have the title deeds of the land they are settling on, so cannot invest in improvements. In general, respondents observed a lack of government commitment to supporting fishers (see Chapter 9).

Notes

1. Stirling 2009; Leach et al. 2010.
2. Arora et al. 2019.
3. Bijker et al. 2012; Nelson 1994; Foxon 2011.
4. Arora and Stirling 2021; Arora et al. 2019.
5. Kumbamu 2020.
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7. Stirling 2009; Arora et al. 2019.
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22. Witte et al. 1999.
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24. Mukasa et al. 2019; Smith 2017.
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26. KMFRI 2019.

> CHAPTER 9

Misalignments between pathways and SDGs

Exploring plural views on how different STI pathways can address SDG challenges

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Footnotes for this chapter are on page 112. A full list of references can be found on page 140.

OVERVIEW

We gathered and analysed different stakeholders' views about how well the STI pathways in our three case studies (see Chapter 8) can address SDG challenges.

- For our India case, we concentrated on two pathways to develop rice seeds for climate resilience and wider agricultural sustainability
- In Argentina, we focused on two pathways for producing scientific knowledge to address the Chagas disease
- In Kenya, we considered three STI pathways to address illegal fishing and overfishing in the Lake Victoria region

In each case, our research directs attention to plural perspectives on diverse pathways. These plural perspectives enabled us to highlight areas of disagreement and agreement – with key implications for policy.

This chapter explores the alignment between the science, technology and innovation (STI) pathways described in the case studies in chapter 8 and the priorities and issues embedded in the Sustainable Development Goals (SDGs). Rather than aiming at a definitive view about the contribution of an STI pathway, we analyse the plural perspectives of different stakeholders, and the various uncertainties and ambiguities that arise. To uncover these divergent perspectives, we used a method known as multi-criteria mapping (MCM).[1]

Our approach

MCM employs a software tool developed to understand a complex issue from different points of view. For the STRINGS research, MCM allowed participants to appraise specific STI pathways as options for addressing SDG challenges.

MCM helps collect both quantitative and qualitative information, linking less tangible qualitative data with quantitative assessments. The aim is to broaden the scope of appraisals by building on the plural values, priorities, experiences, interests, skills and knowledge of research participants.

The advantages of plural perspectives

Plural perspectives mean that MCM avoids engineering a singular consensus. As a result, greater confidence is justified around those aspects where different participants' perspectives are actually found to be in agreement. Such outcomes are more robust than those based on fixed survey questionnaires that are designed to produce singular conclusive answers.

Our results can also help illuminate wider political debates about the reasons for contrasting views on the alignment of STI pathways with the SDGs. In this way, we take seriously key differences of opinion between participants. Such disagreements can then serve as motivations to open up a wider diversity of STI pathways.[2]

MCM in action

In India and Argentina, we used MCM in individual interviews with farmers, extension workers, scientists, policymakers and representatives of civil society organizations. In Kenya, we used the method at a workshop attended by 22 participants, including aquaculturists, small-scale fishers, academics and representatives from local government and civil society groups. Our participants appraised the STI pathways in the first half of 2021, but it is worth noting that the pathways themselves are by no means static. They involve co-evolving techno-scientific, socioeconomic, political and ecological changes (as described in Chapter 8).

Articulating the issues

In all three cases, we described the STI pathways for the participants (see Boxes 9.1, 9.2 and 9.3). Based on these descriptions, participants appraised the pathways according to the sustainability criteria that they themselves defined and deemed important. For each case, we grouped the criteria defined by the participants into three to seven issues related to the SDGs.

Mapping uncertainty

Participants provided both an optimistic score and a pessimistic score for each pathway's performance in relation to each issue. An optimistic score reflects how well they expected a pathway to perform under favourable conditions. In contrast, a pessimistic score is an appraisal of a pathway's expected performance for an issue under scenarios that are unfavourable. We also asked participants to describe the conditions under which they expected their optimistic and pessimistic scores to be realistic estimates. We define as uncertainty the interval between participants' pessimistic and optimistic scores.

Differences between perspectives

Rather than analysing each participant's perspective individually, we grouped the appraisals in each case study based on participants' professional backgrounds. We interviewed only a small number of participants for each perspective, so no perspective can be considered representative of a whole group. Our main aim here was to highlight differences among perspectives as well as points of agreement.

OUR CASE STUDIES

INDIA	Two STI pathways that develop and promote **rice seeds** that are climate resilient
ARGENTINA	Two STI pathways focused on producing relevant knowledge to help tackle **Chagas disease**
KENYA	Three STI pathways to address illegal fishing and **overfishing** in the Lake Victoria region

INDIA

Appraising rice seed pathways in India

We interviewed 20 participants involved in the two STI pathways for rice seeds in Odisha, and divided their appraisals into four different perspectives:

- **farmers** (two women and four men involved in rice production)
- **extension workers** (one woman and three men involved in promoting technology among farmers)
- **researchers** (five men and one woman involved in developing technology for rice)
- **policymakers** (one woman and three men involved in agricultural policymaking)

See Box 9.1 for the definitions of the pathways as provided to the participants.

Participants collectively defined 68 criteria that we grouped into seven issues. These issues are:

- **agrobiodiversity** (relevant to SDGs 15, 13, 3 and 2) relating to the diversity of rice cultivars and conservation of gene pools
- **plant stress** (SDGs 2, 13) relating to the tolerance of rice varieties to biotic and abiotic stresses
- **accessibility** (SDGs 1, 2, 3, 5, 10, and 12) relating particularly to equal access to farming inputs and services by marginalized farmers
- **economy** (SDGs 1, 2, 8 and 12) related to farmers' net income, crop yields, quality and market value as well as national production and income

Box 9.1 / Description of seed pathways in Odisha

PATHWAY 1

Breeding new rice varieties

Key features:

Breeding new rice seeds through formal research and development in Odisha; distribution of newly developed seeds through public and private sectors.

Description:

Promotes high input-intensive model of agricultural development, involving formal scientific breeding techniques to develop new varieties with unique traits like increased productivity and/or stress tolerance.

Promotes seed breeding with minimal participation by farmers in the process (farmers are pictured as buyers of seeds rather than producers).

Tests the performance of newly bred varieties on yield and other parameters, often through multi-location trials in research stations.

Promotes large-scale production and distribution of seeds through (subsidized) public and private sector outlets.

Develops a seed industry comprising public sector, private domestic and multinational firms.

With its focus on yield and similar traits, this pathway can marginalize environmental consequences such as groundwater depletion and biodiversity losses.

PATHWAY 2

Conserving traditional rice varieties

Key features:

Promoting traditional rice seeds for sustainable development through in situ conservation in Odisha; sharing of seeds in farming communities, facilitated by local NGOs.

Description:

Promotes farmers' efforts not only to cultivate 'landraces' (traditional varieties) with limited or no external inputs, but also to help them select and nurture rice varieties with desirable characteristics.

Promotes in-situ conservation of traditional rice seeds on farmers' fields and in community seed banks.

Supports innovative seed conservationists.

Facilitates seed exchange among farmers through informal channels or through events like seed fairs.

Supports women's leadership in managing and sustaining community seed banks.

Supports the formation of decentralized and participatory institutions by farmers at village level, to help nurture traditional seeds, potentially addressing climate change while conserving cultural heritage, nutritional importance and agro-biodiversity at local levels.

Contributes to sustaining ecological integrity by striving for synergy between farmers and nature through agricultural production.

Central roles in this pathway are played by farmers, their organizations and some NGOs.

- **nutrition** (SDGs 2, 5) relating to the rice varieties' nutritional value and their contribution to the nutritional security of consuming households
- **usability** (SDGs 3 and 12) relating to taste, fragrance, consistency and other values attached to rice varieties by user-consumers
- **others**, including criteria such as high research accuracy, plant height, prestige and trait-specific preference

Not all issues were considered relevant by all actors. For example, the issue of agrobiodiversity was not raised by farmers (see Figure 9.1).

Farmers' perspective

The farmers we interviewed considered three issues as salient: usability, economy and accessibility. Farmers' appraisals are depicted in Figure 9.1.

Usability

For the usability issue, farmers ranked the conserving pathway as clearly outperforming the breeding pathway. Qualities such as taste, fragrance and use in cultural rituals of the seed varieties in the conserving pathway were deemed particularly important by farmers. The uncertainty measures for both pathways for this issue were nearly equal, and were lower than the uncertainties around the other two issues.

Economy

For the economy issue, the mean pessimistic score of the conserving pathway is higher than the corresponding score of the breeding pathway. Farmers explained that costs of external inputs are almost zero for the traditional varieties of the conserving pathway. This makes losses due to a poor harvest (pessimistic scenario) more tolerable. In the breeding pathway, farmers must pay for seeds, fertilizers, pesticides and other external inputs. However, if an assured market is accessible, the high yielding varieties (HYVs) of the breeding pathway can lead to a higher net income. For this reason, farmers attached a higher mean optimistic score to the breeding pathway.

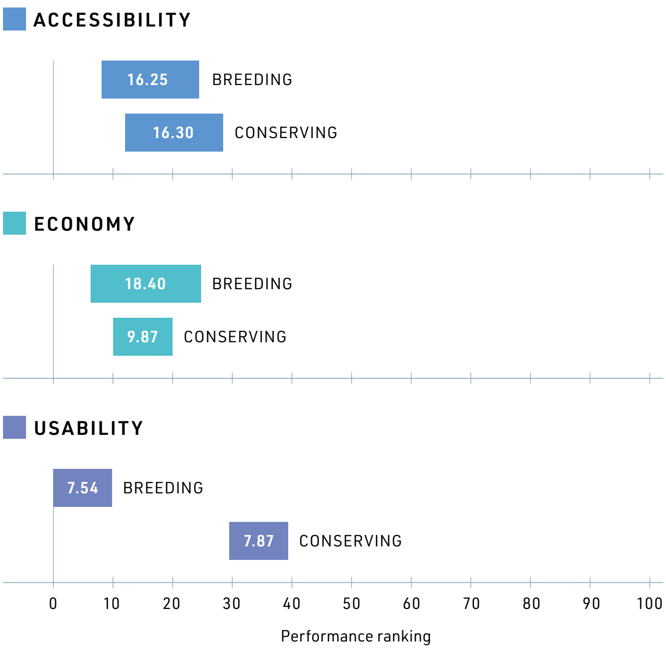
The breeding pathway was also associated with higher uncertainty (see numbers inside bars in Figure 9.1). If rainfall patterns and market conditions are not favourable, farmers can struggle to recover their investments.

Accessibility

Some farmers consider the availability and high cost of HYV seeds as problematic. This explains why farmers appraised the breeding pathway as slightly worse for accessibility than the conserving pathway:

"I am not sure about the source of availability of HYV seeds. If the seeds are available at the block level, then we have to pay a lot of money to get them. Usually, they say that the HYVs can be stored for two to three years but often we cannot use our saved HYV seeds even in the next year. There is also no guarantee that we will be able to get the seeds of the same variety which was grown in the previous year."

Figure 9.1 / Appraisals of seed pathways in Odisha: **farmers' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

> KEY: **Sustainable Development Goals**

SDG 1 No poverty
SDG 2 Zero hunger
SDG 3 Good health and well-being
SDG 4 Quality education
SDG 5 Gender equality
SDG 6 Clean water and sanitation
SDG 7 Affordable and clean energy
SDG 8 Decent work and economic growth
SDG 9 Industry, innovation and infrastructure
SDG 10 Reducing inequality
SDG 11 Sustainable cities and communities
SDG 12 Responsible consumption and production
SDG 13 Climate action
SDG 14 Life below water
SDG 15 Life on land
SDG 16 Peace, justice, and strong institutions
SDG 17 Partnerships for the Goals

Farmers also raised the issue of access to seeds in relation to the conserving pathway.

"Farmers often do not have seeds of shorter duration traditional varieties for lowlands, which are resistant to lodging."

"According to farmers, seeds of the short-duration traditional paddy varieties suitable for summer crop are extinct. They have no access or knowledge about them."

For this issue, the uncertainties associated with the two pathways are nearly the same. Overall, the farmers' perspective highlights the need for greater policy support for both pathways to improve accessibility of varieties. It is also noteworthy that farmers consider the conserving pathway to be less uncertain so far as their local economy is concerned. Finally, for the usability issue (related to SDGs 3 and 12), farmers clearly prefer the conserving pathway.

Extension workers' perspective

Extension workers in non-governmental and governmental bodies engage with farmers at the grassroots on agricultural issues, often in relation to new STIs. Extension workers participating in this study identified accessibility and plant stress as salient issues, as shown in Figure 9.2.

Accessibility

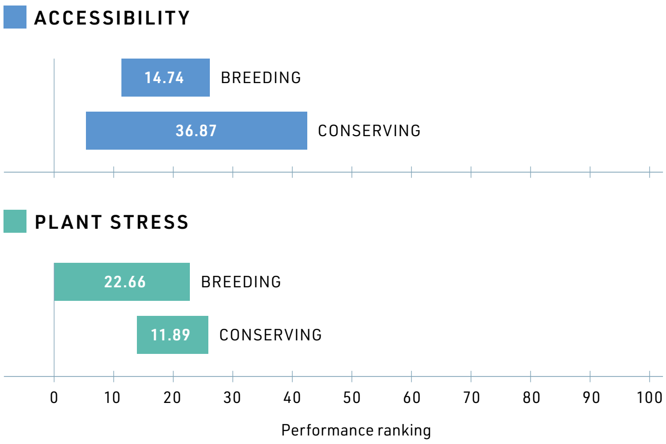
For accessibility, they considered the conserving pathway as the better performing pathway under optimistic conditions, in which on-farm seed savers actively support each other by sharing seeds and knowledge. However, they also associate the conserving pathway with much higher uncertainty than the breeding pathway due to a lack of policy support. For the breeding pathway on the other hand, there is significant government support and private promotion of seeds.

Plant stress

Extension workers associated the breeding pathway with a high degree of uncertainty for the plant stress issue. They argued that, although both pathways include varieties that can tolerate stress, farmers were able to learn very little about the stress performance of HYVs from their own experience since new varieties are introduced every year or two. In contrast, the traditional varieties of the conserving pathway were considered highly tolerant to stress, which explains their higher optimistic score.

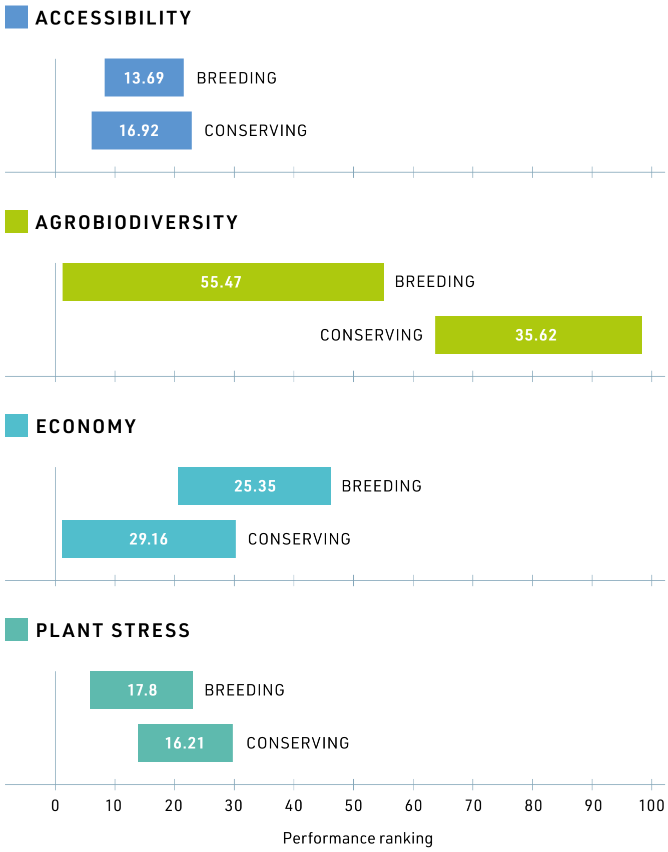
Under pessimistic scenarios, however, some extension workers argued that traditional varieties were not easily available because in situ conservation efforts were rare. Some also felt that the quality of traditional varieties was declining.

Figure 9.2 / Appraisals of seed pathways in Odisha: **extension workers' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Figure 9.3 / Appraisals of seed pathways in Odisha: **researchers' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Researchers' perspective

From the researchers' perspective, four issues were salient: plant stress, agrobiodiversity, accessibility and economy, as shown in Figure 9.3.

Economy

It is only for the issue of the economy that researchers gave a higher mean optimistic score to the breeding pathway. This was due to the expectation of higher yields for seeds bred in laboratories and reflects scientists' beliefs in their own research-based modifications.

"In case of the new breeding strategies, we have...ourselves improved the [high-yielding] quality. We can't change the quality of conserved materials."

Some scientists did nevertheless emphasize the economic benefits of traditional seeds (landraces) in terms of their crop yield and market potential.

"The yield will be almost the same as the landraces are very much adapted to the particular area. They are resistant to stress due to high-tolerance genes."

"Some landraces have excellent grain quality due to which they are much in demand in the market."

Agrobiodiversity

For the issue of agrobiodiversity, researchers' ranked the conserving pathway as far better than the breeding pathway. Here, even the mean pessimistic score for the conserving pathway is higher than the mean optimistic score for the breeding pathway. The breeding pathway was also associated with a higher degree of uncertainty for this issue. Researchers argued that it had resulted in a narrower genetic base and was associated with excessive chemical inputs, which adversely affected soil health.

Plant stress

Researchers recognized the conserving pathway's better tolerance towards many types of stress in micro-environments. However, for large areas, they considered scientists' efforts in the breeding pathway as better at selecting specific genes and developing stress-resistant varieties. These assessments explain the overlap in the performance scores attached to the two pathways for this issue.

Accessibility

For accessibility, researchers' rankings of the two pathways were similar, although the conserving pathway was associated with slightly higher uncertainty. Researchers highlighted availability problems with the HYVs of the breeding pathway, with one stating that *"the reach is still very poor especially for the new stress-tolerant varieties".* They also stated that the landraces of the conserving pathway were locally available, but that knowledge to develop them and institutional support were lacking.

"There is no institutional mechanism to create awareness... about ongoing in situ conservation efforts. The conservation pathway has little support from the research community and there is very limited funding for civil society organizations trying to strengthen conservation efforts."

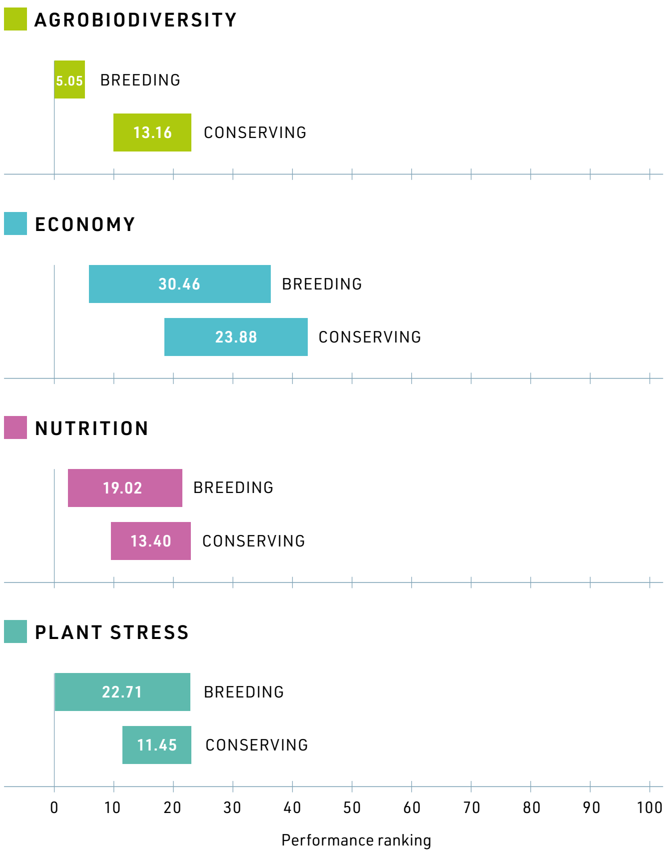
Policymakers' perspective

Policymakers identified four issues as salient: economy, nutrition, plant stress and agrobiodiversity, as shown in Figure 9.4.

Agrobiodiversity

Like the researchers, policymakers considered the conserving pathway to be far better for agrobiodiversity than the breeding pathway. In contrast with researchers, however, policymakers' scores reflect lower uncertainties, particularly in relation to the breeding pathway. The latter is considered to be poor-performing for this issue under all optimistic and pessimistic scenarios.

Figure 9.4 / Appraisals of seed pathways in Odisha: **policymakers' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Other issues

For the other three issues they considered salient (economy, nutrition and plant stress), policymakers rated the conserving pathway as marginally better performing than the breeding pathway under optimistic and pessimistic scenarios. It is also associated with lower uncertainty. Yet there are significant overlaps between the two pathways' scores, and policymakers raised concerns about both pathways.

"Monocropping results in incidence of pests and diseases, which reduces the yield."

"Farmers are cultivating landraces only in marginal lands and they use very little inputs and they are not getting good yields ... Crop management practices and seed quality (in terms of purity) are poor."

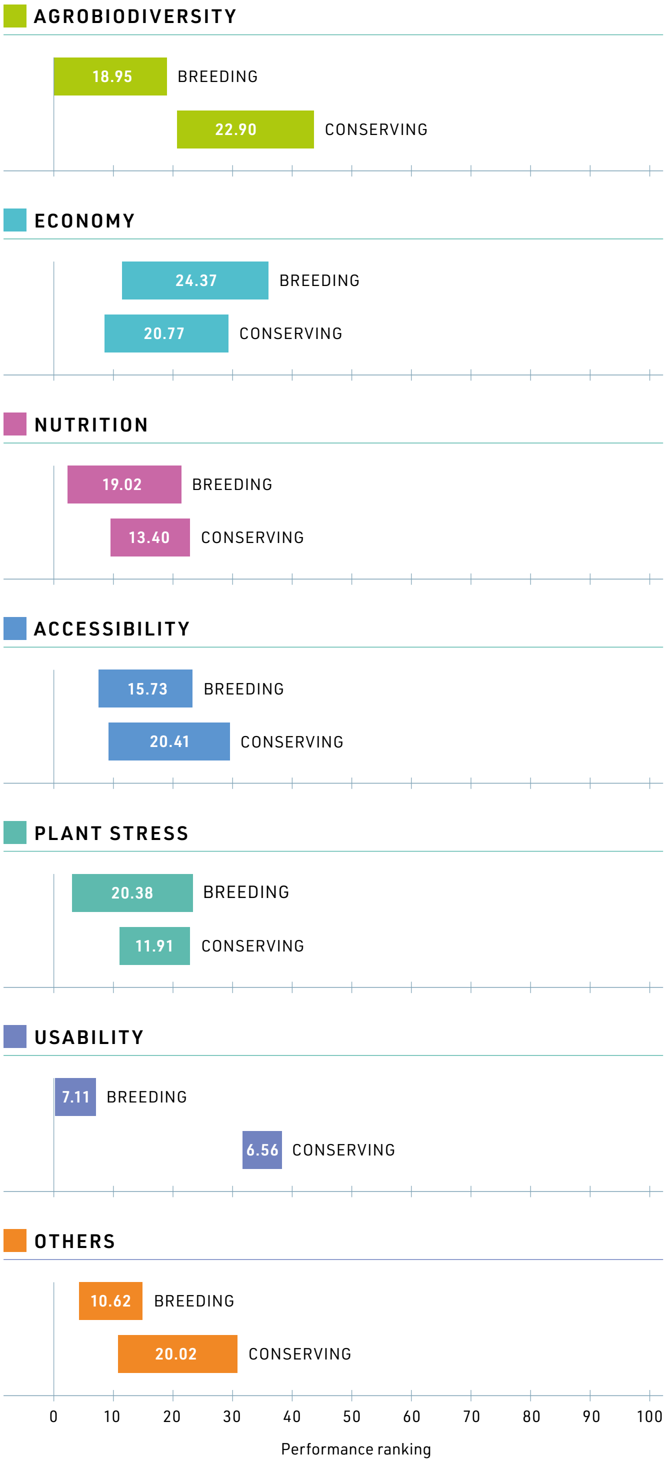
Perspectives combined: implications for policy

There is strong agreement among all MCM participants that the seed conserving pathway is better performing than the seed breeding pathway for the issues of agrobiodiversity (relevant to SDG 15, 13, 3 and 2) and usability (SDGs 3 and 12). Overall, it is only for the issue of the economy that some perspectives consider the breeding pathway to be better performing. For all other issues, the conserving pathway is seen as the better performing pathway under optimistic conditions and often under pessimistic conditions, too. Yet all appraisals of the pathways' performance are associated with significant uncertainties, and their scores often overlap (see Figure 9.5 for a view that combines all perspectives).

It is clear that, in order to promote agrobiodiversity (SDG 15, 13, 3 and 2) and usability (SDGs 3 and 12), greater policy support must be directed towards the conserving pathway, which is currently heavily neglected by governments and the private sector across India.

Policy implications are less straightforward for other issues, where significant overlaps exist. These overlaps indicate that, rather than concentrating policy support on just one pathway, as has been the case in India at least since the 1950s, resources must be equitably distributed between the two pathways. Our results clearly show that the two pathways are appraised as similarly performing under many optimistic and pessimistic conditions for the issues of economy, accessibility, nutrition, plant stress and others. Policy promotion of a diversity of seed pathways may thus be crucial for addressing the SDGs (1, 2, 3, 5, 8, 10, 12 and 13) associated with these five issues.

Figure 9.5 / Appraisals of seed pathways in Odisha: **all participants' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

ARGENTINA

Appraising pathways tackling Chagas in Argentina

We interviewed 23 participants involved in two STI pathways (conventional science and open science) for addressing Chagas disease in Argentina (see Box 9.2 for the definitions of the pathways as provided to the participants). We divided their appraisals into the following perspectives:

- **policymakers** (four women and one man involved in policymaking for addressing Chagas)
- **researchers** (eight women and seven men involved in developing science for Chagas)
- **civil society** (two women and one man)

We asked participants to appraise each pathway using the criteria they considered important. Participants defined 121 criteria, which we grouped into six issues:

- accountability and effectiveness of public **policy and institutions** (related to SDGs 16 and 3)
- **diagnosis and prevention** strategies (SDGs 3, 16, 5 and 4)
- improved **treatments and vaccines** (SDGs 3 and 16)
- **vector control and habitat** (SDGs 11, 3 and 15)
- **education for health** (SDGs 4 and 3)
- **access to health systems** (SDGs 3, 1 and 11)

Unlike in the Indian case study, in Argentina all perspectives considered each issue to be salient, except education for health, which was not raised by the policymakers or civil society representatives.

Box 9.2 / Science pathways for addressing Chagas in Argentina

PATHWAY 1

Conventional science (CS)

Key features:

Research based on technical expertise; results published in academic journals and/or appropriated through intellectual property rights; society gets access to and uses this knowledge through 'technology transfer' mechanisms

Description:

This pathway supports the production of scientific knowledge where research is done by scientific experts in academic spaces.

Projects in this pathway are generally restricted to specific areas of expertise, aiming to develop technical solutions that could be published in academic journals or patented.

To promote the use of the knowledge produced in laboratories, policy schemes support technology transfer to companies and government or civil society organizations, such as public-private research partnerships, or technological licences or contracts of technical assistance.

PATHWAY 2

Open science (OS)

Key features:

Collaborative and open research; collaboration may involve non-academic actors including users; research outputs shared openly (e.g., through open access, communication and engagement with the public)

Description:

In this pathway, OS practices are promoted, which prioritize collaboration between different academic disciplines (interdisciplinary research). Collaboration to produce knowledge with non-academic actors (in civil society, governments and corporations) may also be promoted (transdisciplinary research). Collaboration can also include multi-regional partnerships with other institutions, researchers, policymakers, users and/or volunteers with diverse backgrounds.

This pathway promotes the sharing of results openly (for example, through publications in open-access journals). Beyond results, the process of research may also be opened to the public through open-access databases, the development (and use) of open-source software or hardware, lab notes and so on.

Finally, this pathway promotes extensive engagement, outreach and communication activities to enhance science-society connections.

> KEY: **Sustainable Development Goals**

- **SDG 1** No poverty
- **SDG 2** Zero hunger
- **SDG 3** Good health and well-being
- **SDG 4** Quality education
- **SDG 5** Gender equality
- **SDG 6** Clean water and sanitation
- **SDG 7** Affordable and clean energy
- **SDG 8** Decent work and economic growth
- **SDG 9** Industry, innovation and infrastructure
- **SDG 10** Reducing inequality
- **SDG 11** Sustainable cities and communities
- **SDG 12** Responsible consumption and production
- **SDG 13** Climate action
- **SDG 14** Life below water
- **SDG 15** Life on land
- **SDG 16** Peace, justice, and strong institutions
- **SDG 17** Partnerships for the Goals

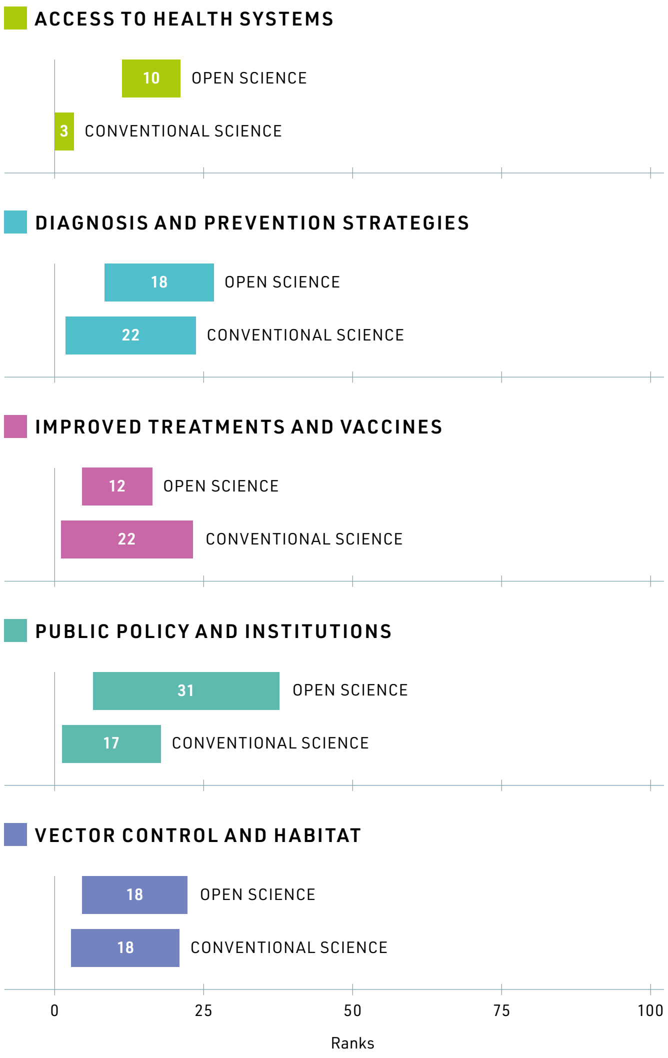
Policymakers' perspective

Access to health systems

Policymakers appraised the OS pathway as clearly better performing for the issue of access to health systems, with its mean pessimistic score exceeding the optimistic score of the CS pathway (see Figure 9.6). One policymaker argued that the OS pathway is more accessible because it tends to be more responsive:

"Open science listens to many voices ... so when you think about the strategy, you are going to adapt it to people's needs."

Figure 9.6 / Appraisals of the two science pathways in Argentina: **policymakers' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Policy and institutions

There is some overlap in the scores for the issue of public policy and institutions, although OS was considered as better performing, particularly under optimistic scenarios, because it uses tools that facilitate interaction and communication between stakeholders. One policymaker described how these connections are lacking in the CS pathway:

"Existing knowledge is not properly transferred (and) linkages between technical staff and politicians are rare."

Yet the performance of the OS pathway was also associated with significantly higher uncertainty by policymakers, perhaps because its communication links are new, untested and less established than the CS pathway's more insular knowledge production practices.

Diagnosis and prevention

For the issue of diagnosis and prevention, the mean optimistic and pessimistic scores for the OS pathway are slightly higher than the corresponding scores for CS, while the uncertainties for the two pathways are comparable.

Treatments and vaccines

It was only for the issue of improved treatments and vaccines that policymakers considered CS to be better performing under optimistic scenarios. Policymakers also associated the CS pathway with higher uncertainty, expecting it to perform worse than OS under pessimistic scenarios. This was largely due to the greater participation of multidisciplinary experts and patients in the OS pathway. One policymaker noted:

"In doing open science with the participation of experts and even of patients, in an optimistic scenario, there would be incentives to search for alternative treatments and possibly also to do research on different presentations (of an available drug)."

Researchers' perspective

Treatments and vaccines

Under optimistic conditions, researchers expected CS to perform better than OS for improving treatments and vaccines (see Figure 9.7). The typical incentive schemes of CS (such as patents) were seen as important, and most researchers were not aware of OS projects developing vaccines.

"Nobody wants, or there is little intention, to patent a drug against Chagas. But patenting a vaccine is more attractive to pharmaceutical companies, because it is more challenging and has more prospect of being able to be used against other parasites."

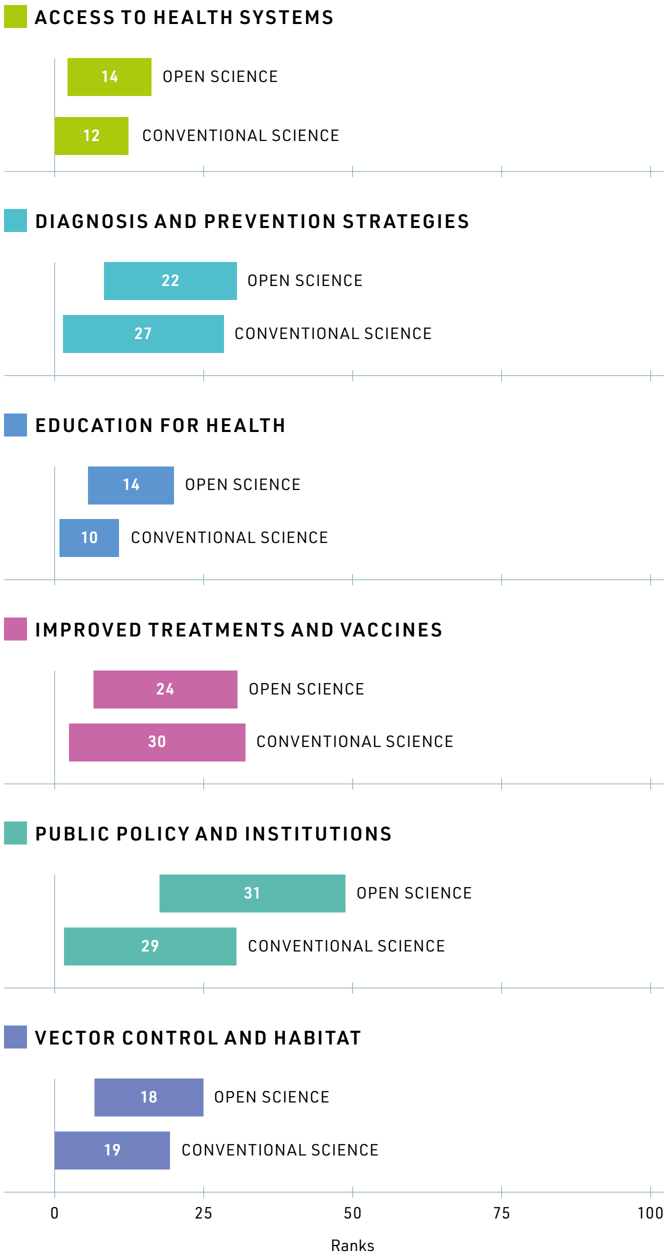
There is, however, considerable overlap in the scores of the two pathways for this issue. Researchers noted the strengths of the OS collaborative, open-access approach – for example, patient participation in clinical trials and open data – making processes more efficient and transparent. They observed the benefits of collaboration between scientists, health teams and patients, which increase opportunities to carry out research and develop alternative therapeutic options.

Other issues

For all other issues, researchers gave the OS pathway higher optimistic and pessimistic scores. Uncertainties associated with the two pathways, across all issues, are generally similar. It is only for education for health that OS was associated with somewhat higher uncertainty, perhaps because of the greater diversity of views (and possible lack of consensus). However, this greater capacity to incorporate diversity was seen as a strength of OS in relation to diagnosis and prevention and vector control and habitat. One researcher said:

"By making the problem visible and by increasing the number of players, open science may create more and better tests than conventional science that always follows the same path."

Figure 9.7 / Appraisals of the two science pathways in Argentina: **researchers' perspective**

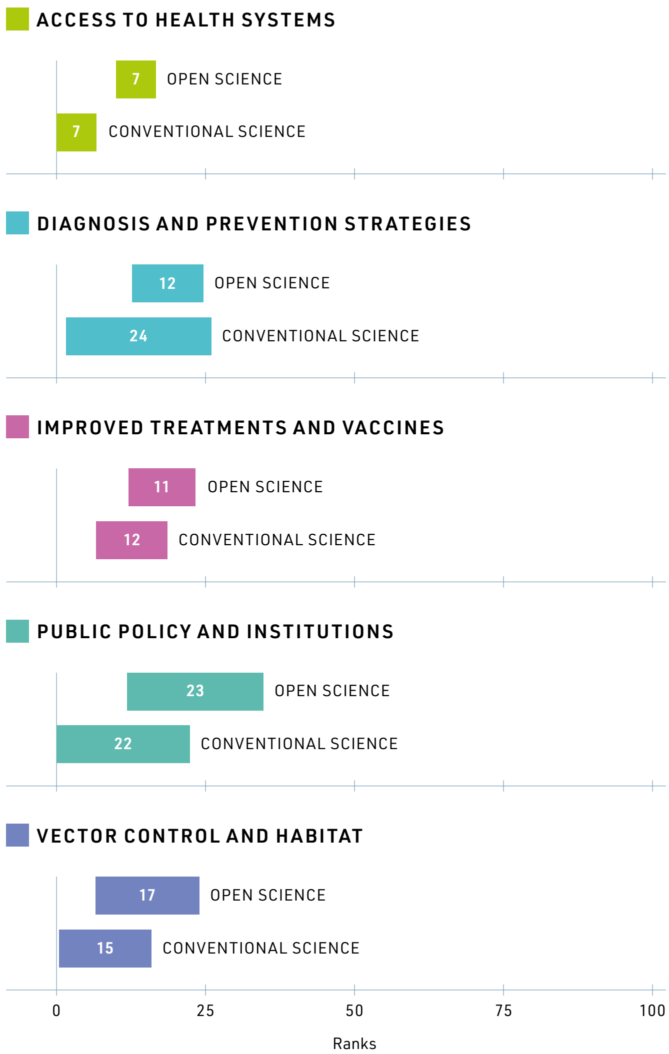


Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Civil society representatives' perspective

Appraisals by civil society actors are very similar to the policymakers' and researchers' appraisals for the issues of access to health, public policy and institutions, and vector control and habitat (see Figure 9.8).

Figure 9.8 / Appraisals of the two science pathways in Argentina: **civil society representatives' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

For most issues, the mean optimistic and pessimistic scores for OS are consistently higher than for CS, and the uncertainties associated with the two pathways are comparable. According to this perspective, it is the OS pathway's inclusion of different disciplines that makes it more aligned with addressing socio-environmental challenges.

"[Open science is] an innovative approach which incorporates other disciplines... [Chagas is] a social problem, a neglected disease with a sanitary dimension, which a strictly medical approach does not take into account."

Diagnosis and prevention

On the issue of diagnosis and prevention strategies, civil society participants attached a slightly higher mean optimistic score to the CS pathway. This may be due to the participants' emphasis on the importance of early diagnosis, which they linked to CS. Civil society actors also associated CS with much higher uncertainty (and a lower pessimistic score) than OS, due to its constitution by a private sector driven primarily by profit rather than by the purpose of widespread social wellbeing.

Treatments and vaccines

For the issue of treatments and vaccines, civil society actors, unlike policymakers and researchers, ranked the OS pathway as generally better performing, discounting the argument for the necessity and efficacy of market incentives in developing new drugs and vaccines. Problems with the dominant CS pathway were observed by a civil society participant as follows.

"There are difficulties in the continuity of the treatment, which requires a thorough follow-up. There are problems with access to the health system for people living far from urban areas...If treatment is not guaranteed continuity, it is not successful."

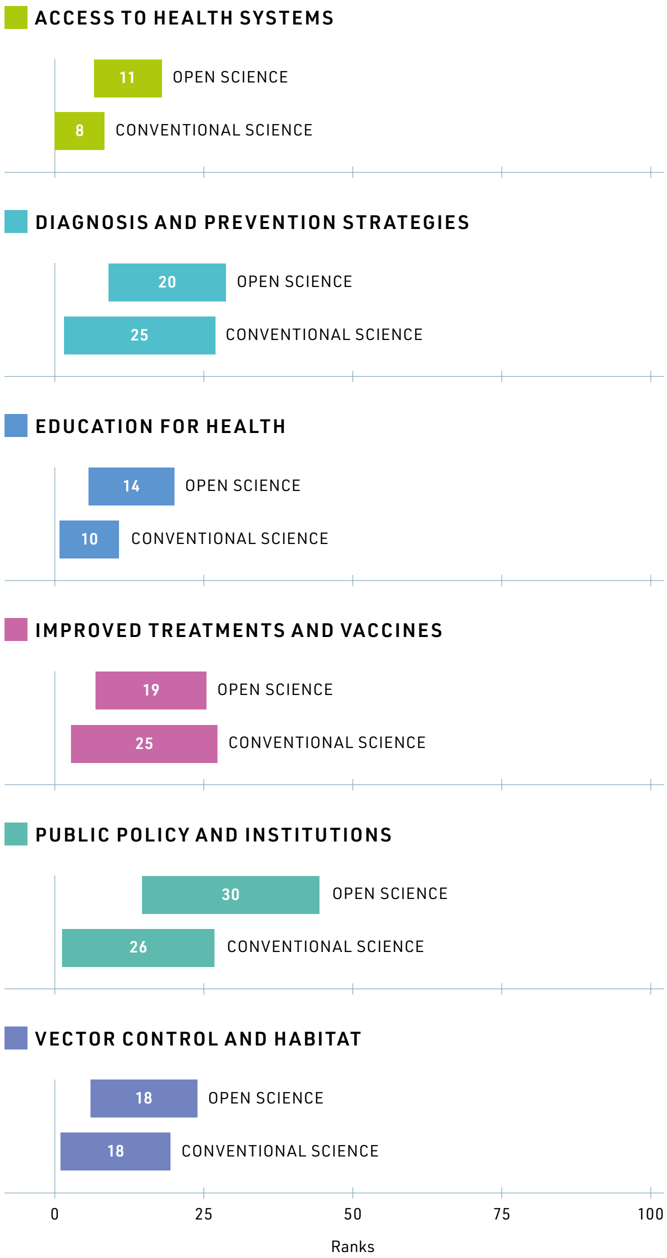
Because the OS pathway includes a wider diversity of voices, it was considered a better way to address the barriers affecting continuity of treatment.

Perspectives combined: implications for policy

Overall, participants showed a general preference for the OS pathway. This level of agreement is rarely observed in an MCM exercise. For Chagas in Argentina, however, it is not surprising, considering the widespread disappointment with the dominant CS pathway.

The policy implications are therefore straightforward. It is important to direct greater policy support towards the currently marginalized OS pathway. It is only for the issue of treatments and vaccines that two of the perspectives consider the CS pathway to be somewhat better performing. However, in the case of Chagas in Argentina, the expected effects of the CS pathway's competitive incentives in fostering new drugs and vaccines have unfortunately not materialized.

Figure 9.9 / Appraisals of the two science pathways in Argentina: **all participants' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

KENYA

Appraising STI pathways to address fishing conflicts in Kenya

In Kenya's Lake Victoria (LV) region, we held a workshop with 22 participants. Using MCM, the participants appraised the effectiveness of the three STI pathways – cage aquaculture, pond fish farming, and monitoring control and surveillance (MCS) – for addressing conflicts related to overfishing and illegal fishing. The descriptions of the pathways provided to the participants are in Box 9.3.

We gathered the views of all workshop participants and grouped them into the following plural perspectives, according to the background and experience of the participants:

- **researchers** (two men)
- **aquaculturalists** (two women and five men)
- members of the wider **local community** (three women and six men)
- local and national **government** officials (four men)

Box 9.3 / Description of STI pathways to address overfishing conflicts in Kenya

PATHWAY 1

Pond fish farming

Key features:

On-farm based with high potential for participation by women; environmentally-sensitive; highly reliant on other farming activities (e.g. production of fish feed and fingerlings)

Description:

Pond fish farming is increasingly practised and is attracting policy attention as a socioeconomic activity to reduce pressure on the inland capture fisheries and address food and nutritional security in the Lake Victoria region.

It helps to diversify economic activities and reduce competition and conflicts. Involving use of traditional and modern technologies (and techniques) of fish production on private land/farms, pond cultures are being developed and managed by an increasing population of women who get access to credit and training provided by national and local governments as well as international partners (donors). Two main types of ponds common around the Lake Victoria are earth and aluminium, with a variety of technologies including hydroponics and digital farming.

Pond fishing is stimulating increased production of crops such as maize, cassava and rice, thus helping to diversify local agriculture, with potential for building resilience against traditional disasters such as drought and reducing the import of crops from neighbouring Uganda and Tanzania.

PATHWAY 2

Monitoring, control and surveillance (MCS)

Key features:

Co-management; participatory approaches involving local fishers, fishery officials and community leaders as well as associations/cooperatives

Description:

This pathway involves the formation of, or support for, associations like beach management units (BMUs), led by local fishers, particularly artisanal ones, and community leaders.

Using a community-based, consultative approach, associations adopt norms to monitor and control overfishing in inland capture fisheries. They share information about changes in fish stocks and help set voluntary restrictions to fishing during certain seasons in certain zones of the lake. Associations use social networking and smartphones to promote awareness among fishers and other local communities about the impact of overfishing (and its relation with illegal and unregulated fishing) on food security and local economies.

In addition to voluntary MCS, there is policing of overfishing. There is use of modern technologies such as drones, satellites, motored boats, helicopters and artificial intelligence. Formal judicial institutions settle disputes between fishers and government regulatory agencies, and issue penalties to offenders. MCS here is implemented through engagement with local community associations such as BMUs.

PATHWAY 3

Cage aquaculture

Key features:

High potential for community-based farming; high potential for youth employment; co-existing with inland capture fisheries

Description:

Cage culture/farming in Lake Victoria and in the rivers in the Basin is being promoted by national and local governments as well as financing institutions because of its potential to reduce pressure or overdependence on inland capture fisheries, and thus help to address degradation of the lake ecosystem and improve food and nutritional security.

Through construction of cages, production of feed and fingerlings and fish processing, local youth are being employed. Some fishers, particularly industrial ones, are moving out of inland capture activities and investing in cage cultures.

Technologies such as genetic breeding, digital applications, CCTV, geographic information systems and artificial intelligence are being used in commercial farms while traditional fishing production is used in small-scale cages around the lake.

Cage farming is largely governed by laws and regulation for inland capture fisheries.

Participants defined several criteria for appraising the STI pathways. We grouped these into three main issues:

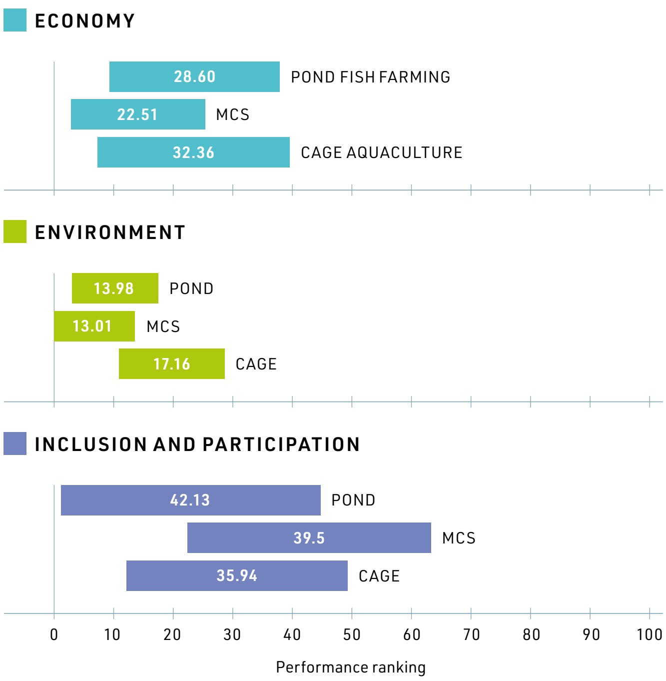
- Social **inclusion and participation**, related to how well a pathway supports the interests and voices of marginalized stakeholders (relevant to SDGs 10, 12 and 16)
- **Economy**, related to the costs associated with technologies, technical standards, labour demand and economic benefits (SDGs 1, 8 and 12)
- **Environment**, related to the lake's ecological condition and preventing extinction of fish species (SDGs 14 and 3)

Researchers' perspective

Environment

Researchers appraised the cage fishing pathway as the most effective way to address environmental issues, as shown in Figure 9.10. However, cage fishing is also associated with slightly higher uncertainty than the other two pathways, due to the fact that there are no clear guidelines or policies for sustainable cage management, as many researchers noted.

Figure 9.10 / Appraisals of the three pathways in Kenya: **researchers' perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Economy

For the economy issue, researchers appraised the MCS pathway as performing slightly worse than the other two pathways, in both optimistic and pessimistic scenarios. One researcher justified this by pointing to the lack of support for this pathway:

"[MCS] lacks appropriate resource allocation by county and national governments and even when they do so, there is lack of stakeholder contribution to their work."

Inclusion and participation

For the social inclusion and participation issue, researchers assigned the highest scores to the MCS pathway. One researcher observed:

"The governance structure [of MCS] can be designed to include local bodies such as beach management units and local opinion leaders, to ensure that MCS is strictly implemented to reduce conflicts. Also, the local units know each other and they can easily detect who is using unpermitted gear for fishing. If the BMUs are empowered, they can govern themselves to enact MCS very effectively on local beaches."

In contrast, the inclusion of marginalized local actors was considered more difficult in the cage and pond pathways due to the high upfront costs. The average cost of a cage in Kenya's LV region, for example, is an estimated US$ 2,600,[3] which lies beyond the reach of most small-scale fishers.

Aquaculturalists' perspective

Inclusion and participation

The aquaculturalists gave similar scores to each of the three pathways for the inclusion and participation issue (see Figure 9.11). The cage pathway received higher pessimistic and optimistic scores by just a small margin. According to a representative of the Cage Fish Farmers' Association of Kenya, the cage pathway can help achieve social inclusion, particularly for women and youth, if it is well-implemented and properly financed.

Economy

Aquaculture practitioners appraised the cage fishing pathway as the best performing for the economy issue. One considered cage fishing "the surest way of ensuring economic well-being." Even though the cage pathway is also associated with the highest uncertainty, one fisher stated that income from cage fishing is stable throughout the year under optimistic economic conditions:

"Assume I have multiple cages and harvest at various intervals, I will be economically secure throughout the year. I will therefore have zero need to conflict with my colleagues."

The situation may be less favourable in situations where cage fishers do not have access to multiple cages or where they cannot find adequate labour to harvest at regular intervals.

The MCS pathway was rated lowest by aquaculture practitioners for the economy issue. Under pessimistic conditions, some saw MCS as little more than a vehicle for advancing corruption (such as when illegal nets found by officers are confiscated and later sold). Such actions were said to lead to conflicts between beach management units and fisherfolk as well as between fishers.

Environment

For the issue of the environment, the aquaculturalists once again rate the aquaculture pathways (pond and cage) as somewhat better performing than MCS, with cage aquaculture receiving the highest optimistic and pessimistic scores. Corruption was cited again as a justification, with participants claiming that most government funds allocated to MCS were misappropriated.

Local community perspective

Unlike the aquaculturalists, who seem to favour the cage pathway, other local community members (including fish traders, artisanal fishers and representatives of religious institutions) did not express a clear preference for any one pathway, particularly for the issues of the environment and inclusion and participation. See Figure 9.12.

Inclusion and participation

For the inclusion and participation issue, pond fish farming was associated with lower uncertainty than the other two pathways. Participants observed that conflicts around the management of ponds are likely to be minimal, because most ponds are located within private lands. The highest uncertainty (and the lowest mean pessimistic score) for this issue was associated with the MCS pathway, with one representative observing that:

"Community is not fully engaged in the process of setting up systems and enforcement of the policies."

Economy

The local community perspective considered the MCS pathway as the best performing for the economy issue, but only under optimistic conditions. One local fish trader explained the lower optimistic score associated with the pond fishing pathway by noting the low yields and poor quality of the fish that are farmed in ponds:

"Size of fish and quality is small and not preferred [in the market]."

Figure 9.11 / Appraisals of the three pathways in Kenya: **aquaculturalists' perspective**

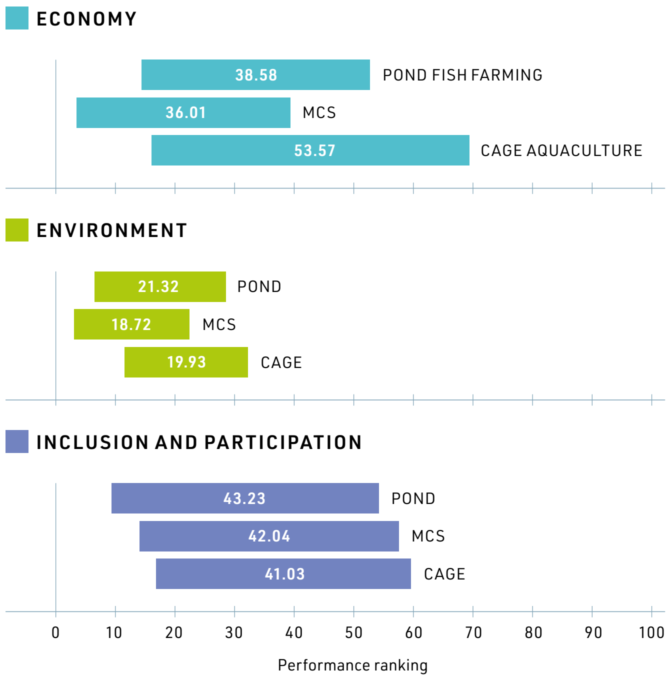
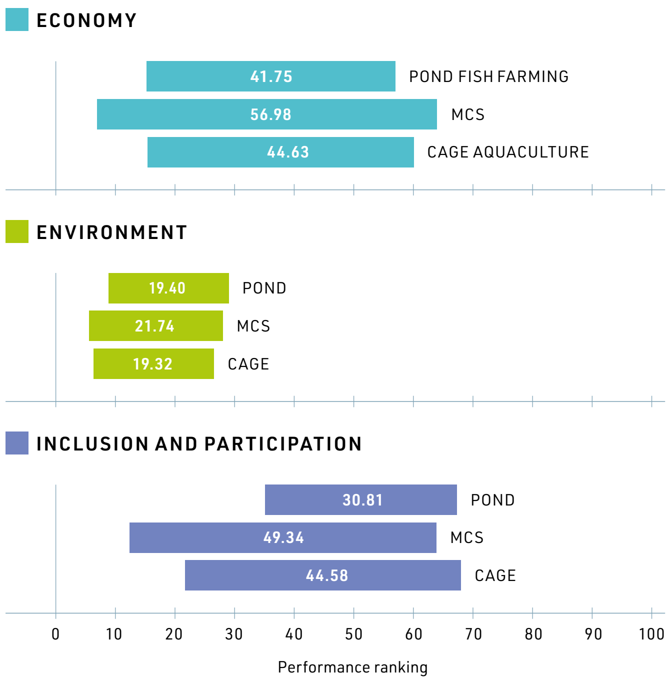


Figure 9.12 / Appraisals of the three pathways in Kenya: **local community perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Local and national government perspective

Economy

Unlike the local community representatives, government officials considered the two aquaculture pathways as the best performing (under both optimistic and pessimistic scenarios) for the economy issue, as shown in Figure 9.13. Cage aquaculture, for example, was expected to increase fish production and reduce conflicts.

Some government officials also expected positive economic results from the MCS pathway, which they felt curbed illegal fishing and increased the size and quality of fish capture, fetching higher prices. One senior official noted:

"Monitoring and surveillance is the ultimate medicine to curb conflict in the lake. The government should endeavour to empower the enforcement departments to ensure that fishing is sustainable."

Environment

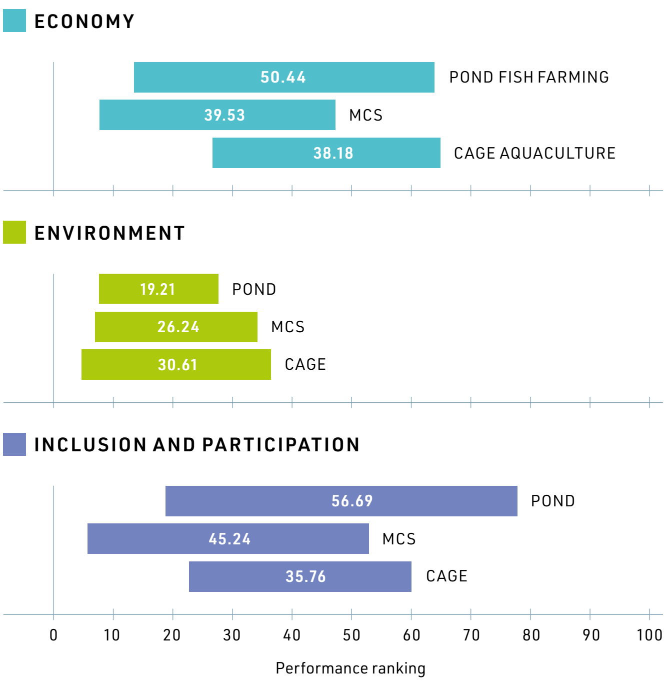
For the issue of the environment, the mean optimistic score of the MCS pathway was comparable to the highest score associated with the cage culture pathway. Pond farming was ranked lower under optimistic scenarios. It was also associated with the lowest uncertainty, perhaps because private ownership was seen as less likely to lead to coordination problems between different actors (as compared to the other two pathways).

Inclusion and participation

For the inclusion and participation issue, like the economy issue, government officials attached the highest uncertainty to the pond farming pathway. While observing the potential of ponds for increasing production, they were concerned about the availability of land and fish feed, as well as the lack of a supportive policy environment under pessimistic scenarios.

"Insufficient land and inadequate sensitization from relevant ministries have rendered pond culture unrealistic."

Figure 9.13 / Appraisals of the three pathways in Kenya: **government perspective**



Each bar represents the range from the average optimistic score to the average pessimistic score ascribed to a pathway. The difference between these two scores is a measure of uncertainty, shown as the number inside each bar.

Perspectives combined: implications for policy

In general, respondents observed a lack of government commitment to supporting fishers, particularly small-scale pond farmers. Fishers reported a lack of trust in state-led governance processes in relation to all three pathways. A re-orientation of state-led governance is therefore required if the three pathways are to effectively address the SDGs.

While participants ranked the MCS pathway somewhat lower than the two aquaculture pathways, there are significant overlaps between the three pathways' performance scores, and the uncertainties associated with the three pathways are broadly similar across plural perspectives.

The participants' plural perspectives indicate that all three pathways could potentially be aligned with the economic, environmental and participatory/inclusive priorities related to the SDGs. There is therefore a need to direct policy support to diverse STI pathways in order to address fishing conflicts in the Lake Victoria region of Kenya.

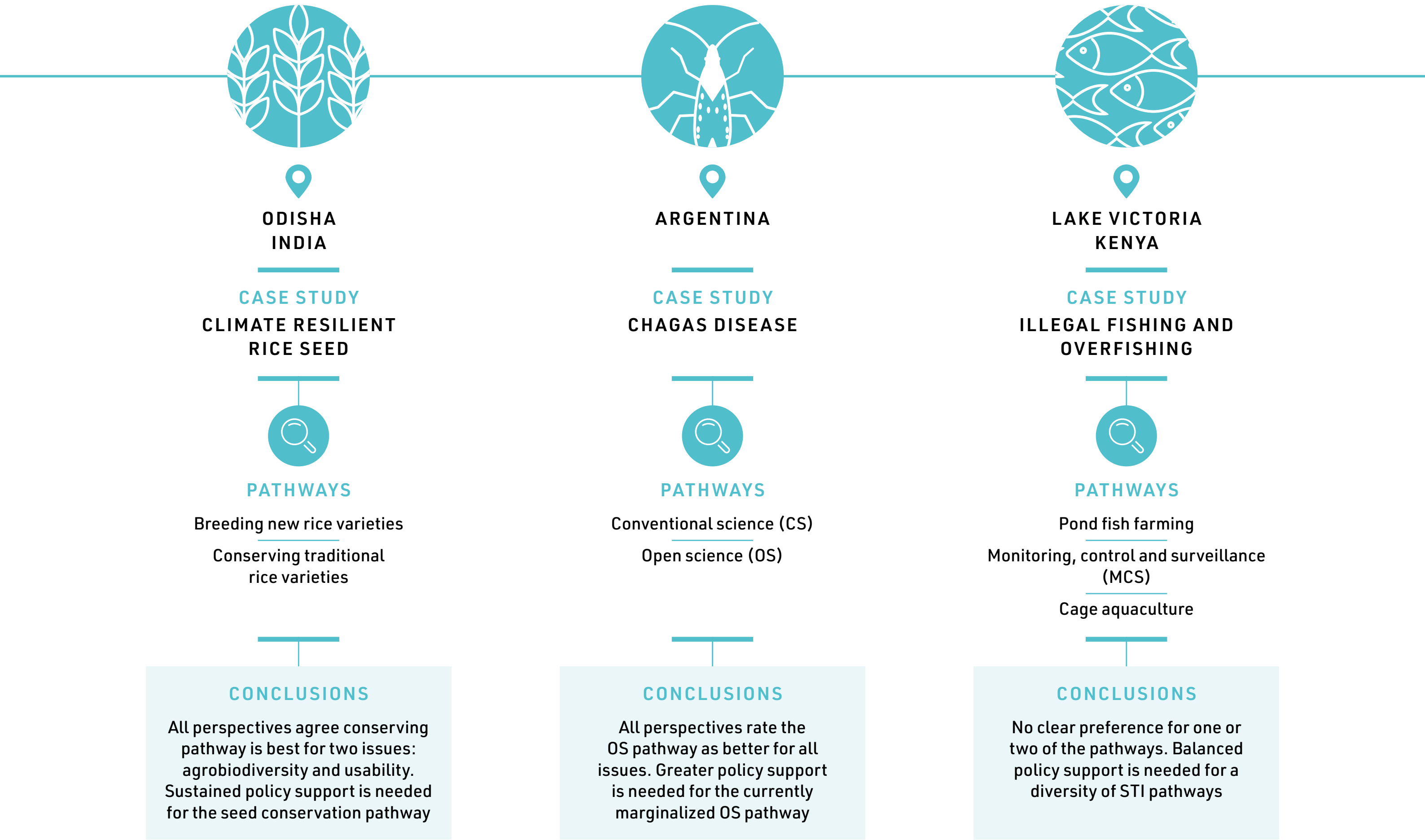
Conclusions

The MCM analyses in each of the three countries show how different groups of stakeholders offer plural perspectives on the alignment of diverse STI pathways with priorities and challenges embedded in the SDGs.

It is only in Argentina that the plural perspectives are in agreement with each other, rating the open science pathway more highly across a whole range of SDG-related issues. This result of rare agreement revealed by an MCM exercise might be due to the widespread disappointment with the dominant conventional science pathway's attempts to address Chagas.

In contrast to Argentina, our results in India and Kenya yield more complex pictures. In India, four different perspectives agree unambiguously about the superior performance of the seed conserving pathway for the issues of agrobiodiversity and usability. This highlights the need for sustained policy support for this much-neglected pathway to meet SDGs 15, 13, 12, 3 and 2. However, the consensus for focusing on that pathway alone for the other SDG-relevant issues is less clear.

Figure 9.14 / A summary of plural perspectives on diverse STI pathways



Similarly, in Kenya, while the cage aquaculture pathway is considered somewhat better performing under optimistic conditions, by some perspectives for some issues, there is no clear preference for just one or two of the pathways. Therefore, our results point to the need for balanced policy support for a diversity of STI pathways to address SDG-related issues.

To realize such support, a wide range of policy and institutional combinations may be required, transcending modern sectoral categories that separate environmental challenges from social and economic concerns. Thus, departments that make social and economic policies must include the perspectives of actors who speak for the natural environment, including ecologists and other scientific experts, grassroots activists and community organizations.[4]

In the same way, environmental policymaking must seek to include plural perspectives, particularly of the most marginalized actors in society. Such perspectives are often articulated clearly in social movements and civil society organizations at the grassroots, which must play a central role in steering a diversity of STI pathways towards alignment with the priorities and values embedded in the SDGs.

Notes

1. Stirling and Coburn 2014.
2. Stirling 2008; Arora et al. 2019; Arora and Stirling 2021.
3. Orina et al. 2018.
4. de Hoop and Arora 2021.

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

> CHAPTER 10

Diversity and plurality

Strategies to address complexities in aligning STI and the SDGs

AUTHORS

Andy Stirling
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OVERVIEW

- There is a need to focus on the plurality of worldwide interests, values and understandings and to aim for a diversity of possible STI responses to complex SDG challenges.
- A diverse research and innovation portfolio enables sensitivity to context.
- Deliberate diversification is more robust than the conventional policy aim of identifying a single 'optimal' STI pathway.
- STI portfolios should always be subject to rigorous technical analysis and vigorous democratic oversight.
- Effectively addressing sustainability challenges involves building capabilities to challenge the incumbent power that often concentrates around entrenched, unsustainable STI pathways.

Footnotes for this chapter are on page 118. A full list of references can be found on page 140.

Earlier sections of this report have explored various deep-seated dilemmas around aligning STI pathways with the social, economic and environmental imperatives embodied in the SDGs. A key issue is the importance of attending to the **plurality** of worldwide interests, values and understandings, which relate both to STI activities and to the prioritizing of issues encompassed in the SDGs.

In addressing this plurality of sustainability challenges, this report highlights some neglected real-world governance dilemmas in seeking to align STIs with the SDGs, as follows:

- SDG goals, targets and metrics encompass **multiple dimensions** of intersecting social, economic and ecological challenges
- Each dimension, and each relation between dimensions, displays **variabilities, uncertainties and ambiguities** that involve divergent understandings and perspectives
- Each potential STI pathway that may offer a response to these dilemmas may also be reasonably understood and evaluated in a **multiplicity of ways**

Diversity among STI responses

These dilemmas of plurality indicate the importance of a **diversity** of possible responses to SDG challenges. At first sight, this looks like it could compound the policy challenges. Real-world politics, with its entrenched structures and gradients of power and privilege, can put pressure on analysts and academic researchers to represent results in ways that artificially simplify the pluralities of the SDGs themselves and exclude diversity in the possible responses.

Yet on the other horn of this 'real-world' political dilemma, there are the '*real* real-world' complexities of sustainability challenges and possible research and innovation responses themselves. The key questions are, therefore: What practical strategies are available for responding to the irreducible complexities around alignments of STI with the SDGs? What operational options exist for dealing robustly with challenges of plurality, uncertainty and ambiguity without simplifying or concealing these inconvenient truths?

Deliberate diversification of responses

Fortunately, there is a clear pragmatic option that can address these challenges in fundamental ways. Although it is neither a panacea nor without its downsides in particular contexts, this practical response is diversity itself.[1]

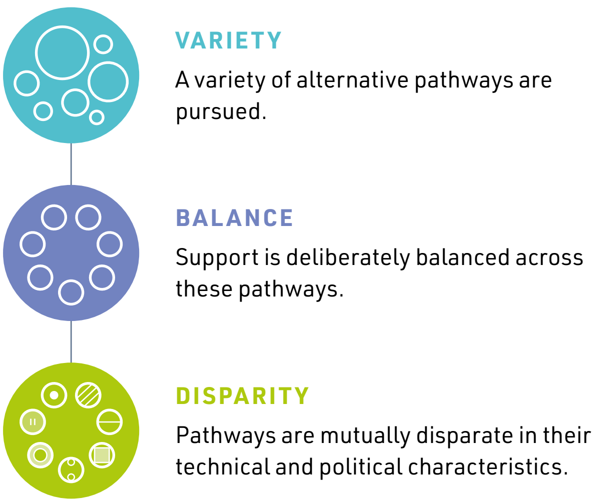
Through deliberately pursuing a diversity of responses to SDG challenges, governance of STI for the SDGs can:

- be sensitive to different contexts
- hedge against uncertainties
- accommodate ambiguities
- mitigate adverse forms of lock-in (that is, the rules and infrastructures that are set up for a particular way of doing things and keep it that way)
- foster creativity and accelerate deeper forms of learning in research and innovation themselves

By deliberate diversification, we mean placing explicit value on the quality of diversity in research portfolios and innovation programmes designed to address sustainability challenges. By 'diversity' in STI pathways, we refer specifically to the following three key qualities (see Figure 10.1):[2]

- A **variety** of alternative pathways are pursued. 'Variety' is an integer, simply counting the number of different pathways that might be categorized.
- Support is purposefully **balanced** across these pathways. 'Balance' is a set of fractions that add up to one, reflecting the relative prioritizations across these different pathways.
- Pathways are mutually **disparate** in their technical and political characteristics. 'Disparity' is the degree of salient difference between different pathways.

Figure 10.1 / Diversity in STI pathways: the three key qualities



The value of a diverse portfolio

By considering the properties of variety, balance and disparity, it becomes possible to derive a rigorous analytical tool to measure how much and what kinds of diversity might offer the best response to the challenges of aligning STI with the SDGs.[5]

Using this framework to systematically modulate variety, balance and disparity in a suite of STI pathways for a given SDG is more easily achieved than seeking to identify a single 'best' response.

Through these entangled qualities, a diverse research or innovation portfolio can begin to address the array of challenges described above, as follows.

- By embracing different social and technical attributes, a diverse portfolio can **address context-sensitivities** in ways that are not possible with any single pathway.[4]
- By incorporating features that address contrasting eventualities, diversity can help **build a response pool that is more resilient** in the face of deep uncertainties than the singular options often prioritized in mainstream policy analysis.[5] For instance, disparities between wind, solar and geothermal power mean that no single cause is likely to disrupt them all at the same time in the way that geopolitical or regulatory developments can affect coal, oil and gas simultaneously.
- By spanning characteristics that appeal to contending political, economic or sociocultural interests, diversity may be able to **accommodate seemingly irreconcilable ambiguities.**[6] For instance, rural and urban conservatives and progressives may not be able to agree that any single energy strategy is 'best'. But a diverse portfolio of renewable options may collectively accommodate this plurality of perspectives and interests.
- By supporting disparate research and innovation 'niches', diversity can **mitigate adverse forms of path dependency and lock-in** around any particular dominant pathway.[5] For instance, social and grassroots innovations for cultivating, preparing and distributing sustainable local produce can reduce dependency on industrial monocultures driving highly processed, wasteful food consumption.
- By promoting connections and overlaps between communities, diversity can **foster greater creativity and accelerate deeper learning** between pathways.[7]
- Diversification among STI pathways can also help **address issues associated with spin-off and trickle-down** in the anticipated secondary effects of a project or development. These supposed benefits (for example, artificial intelligence for cities or civil nuclear power) are each shaped to some degree by some primary direction for innovation, such as military logistics or naval propulsion. Characteristics imposed by this original context (for example, hierarchical control in artificial intelligence or concentrated power in nuclear technologies) can constrain and imprint the associated trickle-down or spin-off effects. Promoting greater diversity can help avoid this issue.

A remarkable picture emerges when diversity of STI pathways is characterized in terms of these three properties. For instance, without considering disparity, we would not appreciate how the political-economic, technical, resource and supply-chain attributes of wind power make it arguably more different from both coal and nuclear power than either of these are from the other.[3] So if we ignore disparity, the assumption might be that all pathways are equally different from each other.

The difficulties of diversity

Of course, it is important to be open-eyed about the less attractive attributes of diversity. Diversity in STI pathways is not a free lunch:[8] it does not necessarily come without costs. By definition, deliberate diversification means affording relatively less support for pathways that are seen to perform best and greater support for pathways whose overall performance might seem weaker, but which add to overall diversity.

What diversification means, then, is that the most favoured pathways become less dominant and more marginalized pathways become more supported. From the perspective of dominant pathways, this may appear to be a disadvantage. But from less powerful interests or less privileged perspectives, it may seem like a benefit. Under metrics associated with the dominant view, this will look like a diversity/performance trade-off.

Further practical challenges of deliberate diversification include elevated transaction costs caused by administrative inertia and the difficulty of communications across disparate programmes.[9] For a particular STI pathway that might otherwise have been strongly supported in a portfolio, diversification in favour of other pathways can also involve a loss in economies of scale.[11] Some economies of scope may accrue, but this may mean foregoing the benefits of standardization across the portfolio as a whole,[11] for example, due to increased costs of translating between different formats. In a wider governance context, it is also possible that diversification may obscure broader processes of accountability.[10]

There may also be dangers related to particular types of emphasis on diversity in policy discourse. If the approach to diversity is not systematic, then well-resourced interests associated with poorly-performing STI pathways may use diversity rhetoric to encourage support for failing options. Here, then, it is crucial to recognize that diversity (systematically defined and analysed) is a fundamental property of a portfolio of STI pathways as a whole. Advocacy of diversity that disproportionately promotes some specific individually-favoured innovation pathway is a sure sign of vested interests at work. Diversity does not mean 'do everything', but 'choose openly and carefully'.[10]

Evaluating STI pathways

What all these considerations underscore is that deliberate diversification of STI pathways should be subject to rigorous and transparent technical analysis and vigorous democratic oversight. Fortunately, an approach based on variety, balance and disparity, as suggested here, yields a robust quantitative framework for systematic policy appraisal of the complex relations between diversity and performance in STI portfolios, without vulnerability to manipulation in favour of specific options.[5]

Depending on the nature of the sustainability challenge and the wider political dynamics, policymakers can pick the precise forms and degrees of diversity that are appropriate for specific challenges. The extent to which the advantages of diversification are seen to be outweighed by costs and burdens can then be a matter for transdisciplinary analysis, inclusive participation and wider democratic oversight.[11]

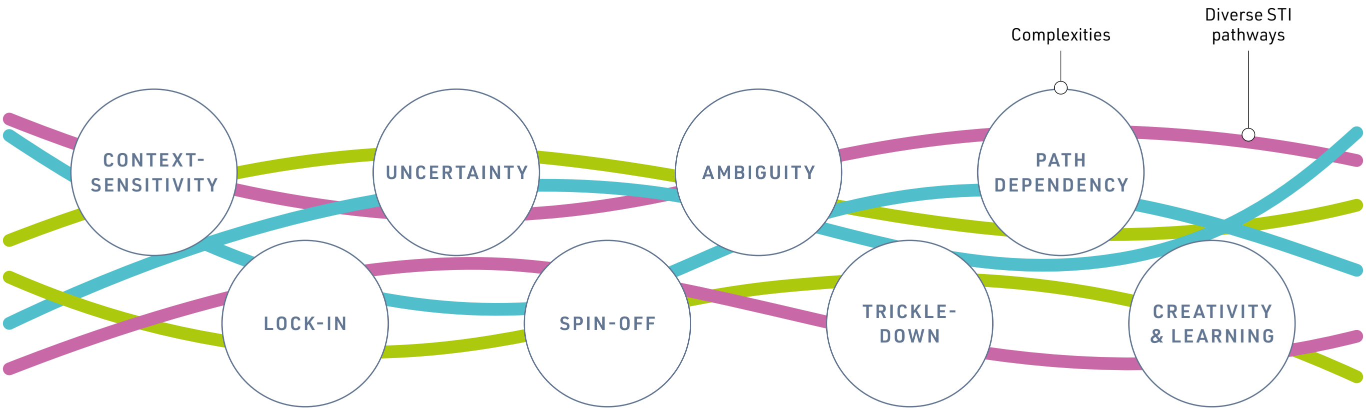
If the net benefits of diversity appear minimal, then governance may indeed prioritize a single STI pathway for the focal SDGs. Where the balance of pros and cons lie on the side of diversity, then more diverse STI portfolios will be justified. More diverse portfolios may be associated with a move from narrow elite policymaking to broader forms of governance involving more marginalized interests and civil society. Either way, what is crucial is that diversity in research and innovation for sustainability becomes the focus of transparent, systematic and accountable attention.

> 'More diverse portfolios may be associated with a move from narrow elite policymaking to broader forms of governance involving more marginalized interests and civil society.'

Deliberate diversification of STI pathways is not about relinquishing rigorous analysis and does not imply that 'anything goes'.[12] Through careful acknowledgement of the real-world complexities identified above, deliberate diversification offers a more robust approach than conventional policy appraisals that tend towards pursuing singular STI pathways.

Where careful empirical attention is given – from a range of perspectives and in both quantitative and qualitative terms – to the attributes of a range of STI pathways, a small number of

Figure 10.2 / Addressing complexities through deliberate diversification



A diverse research or innovation portfolio can help to address the many complexities described above robust pathways will typically emerge as the strongest. Many other possibilities will be seen as manifestly less attractive, irrespective of the perspective. When this situation occurs, it is possible to attach far greater confidence to the more positive pathways than would be the case for analysis aimed simply at engineering closure. Decisions are still taken, but the understandings on which they are based are broader and more robust.

A focus on power and privilege

Ever since the Brundtland Commission in 1987,[12] sustainable development has been recognized as being just as much about participation and democracy in the processes of governance as it is about the various goals, targets and metrics bearing on the outcomes (such as improved water, air and food). The 2030 SDG framework itself reaffirms and further emphasizes that sustainability is as much about process as outcomes.

For the SDGs, this means a direct focus on how patterns of power and privilege operate in relation to challenges of social equality, economic well-being and ecological integrity. In some forms and settings, power of particular kinds offers an essential resource. In other modes and contexts, entrenched power and privilege are among the core problems.[13]

Whatever the context, effectively addressing sustainability challenges involves building capabilities to challenge the incumbent power that is often associated with entrenched, unsustainable STI pathways, such as toxic chemicals, fossil fuels, military approaches to international relations or related nuclear infrastructures.[14]

Whether through quantitative analysis, qualitative deliberation or other forms of mobilization, democracy is in this sense about access by the least powerful to the capacities for challenging power.[15] When power remains unchallenged, it is most likely to be regressive (rather than progressive) in relation to sustainability challenges.[16]

There is a crucial responsibility for international governance of STI to give more systematic attention to the interlinked qualities of plurality and diversity.[14] In this way it is possible to achieve the inclusive access, participatory agency and democratic governance that are intrinsic to achieving more democratic processes and more socially robust outcomes.[17,18]

Tools to map STI pathways onto SDG challenges

In the end, there can be no unequivocal or definitive conclusions concerning the aligning of STI diversity with SDG plurality. Despite political pressures for policy justification, the complex dynamics and ambiguities in research and innovation and in social and ecological challenges will typically preclude simple single prescriptions.[19]

It is impossible to determine exact, final answers to the dilemmas of aligning STI with the SDGs as one might determine precise geometric relations in mathematics, for example.[20,21] But this does not mean that governance processes cannot derive, in robustly qualitative ways, the broad patterns of possible alignments. The resulting practical pictures are 'heuristic' because they explore different reasonable responses, rather than mechanisms to assert particular solutions. Rather than pretending at a single final analytical view, heuristics may offer a more collectively firm basis for further investigation and learning.[22,23] By using an explorative, heuristic approach to align STI with the SDGs, policymakers and funders may obtain a useful sense of the relations between different challenges and pathways, even if the precise details are hazy.[24,25]

As has been mandated in sustainable development frameworks from their very beginning, these plural and conditional analytical mappings need to be complemented by transparent communication, inclusive access, participatory involvement, open accountability and wider democratic governance.[26,27] It is through such ongoing, iterative and interactive processes – firmly grounded in disparate geographical settings around the world – that global research and innovation activities can become better aligned with sustainability imperatives.

Building on the above ideas, the following chapters present:

- the various ways that global governance can better align STI with the SDGs (Chapter 11)
- the use of a tool to enable stakeholders to make their own choices on the relevance of STI for SDGs (Chapter 12)
- our recommended policy interventions to address misalignments between STI and the SDGs (Chapter 13)

Notes

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> CHAPTER 11

Options for global governance

How global governance could help align STI and the SDGs

AUTHORS

Geoff Mulgan

Footnotes for this chapter are on page 124. A full list of references can be found on page 140.

OVERVIEW

This chapter looks at options for global governance to better align science, technology and innovation (STI) strategies , including research and development (R&D) expenditure, with the SDGs. We propose four sets of initiatives:

1. A global **platform observatory** with regular surveys of global R&D, its scale, locations, purposes and impacts
2. More **organized constellations** of funders, interested parties and science policy decision makers to coordinate actions, using open data, open coordination and engagement of users
3. Formal **global funding pools** to combine R&D resources on key global goals
4. Regular **summits and conventions** to promote discussion, absorption and action

Global priorities and the shifting landscape

The shape of global science, technology and innovation (STI) has changed dramatically in the last two generations, with a shift from government priorities – primarily defence – being predominant to a situation in which business plays a much larger role.

In 1960, one-third of all global research and development (R&D) was funded by the US Department of Defense. This investment helped the US develop many technologies which later had other uses, including microprocessors, GPS, touch screens and satellites. The equivalent proportion in 2016 was just 3.6%. Although there is still a strong bias in spending to richer countries, China, the European Union, South Korea, Israel and many other middle-income countries have come to see substantial R&D investment as integral to economic and security policy.

> 'In 2019, the USA's top five tech companies spent $106bn on R&D – more than all of the European Union's governments combined.'

The shift to business-led research is just as striking. In the US, the top five tech firms' R&D investment is now ten times bigger than the top five defence firms. In 2019, the USA's top five tech companies spent $106bn on R&D – more than all of the European Union's governments combined. These companies have become influential in the global governance of many areas of technology, increasingly joined by Chinese firms.

As a result, many recent technologies, including 5G mobile, artificial intelligence (AI), quantum computing, high performance batteries and biotech, have been primarily developed by business, with the military later learning how to adapt and adopt them. Social applications have tended to come much later, if at all. The development of public sector and social uses of mobile phones, for example, was very slow.[1]

The late 2010s saw the emergence of a small 'AI for good' field, including several organizations interested in using AI to support the SDGs. However, there has been very little global debate or shaping of funding allocations and R&D priorities in this area. This echoes the gaps in many other fields, such as food or energy, where there has been little discussion of alternative pathways or how policies for adoption, regulation and experimentation could support them.

The next steps: our recommendations

There are no easy solutions to these problems, given the complexity of the world's innovation ecosystems, the number of players and the diversity of interests. However, it is paradoxical that, in an era when it is easier than ever to share data and knowledge globally, there is so little shared analysis or action. This results in wasted efforts, sub-scale initiatives and misalignments between research spending and public priorities.

In the future, it is possible that stronger institutions at a global level might guide spending, rather as institutions like the International Monetary Fund (IMF) or the World Health Organization steer work in their fields. However, this is unlikely to be feasible in the near term. In the meantime, there is a strong case for much more systematic orchestration of data and knowledge to guide action. We explore four key approaches below.

1

A global platform observatory for STI

A global approach to STI goes with the grain of recent history: the more recently created global entities are often highly specialized, dealing with major issues from migration to epidemics, drugs and organized crime to cybersecurity and security. Already air safety and intellectual property, for example, have specialized organizations that are arguably more adaptable than bigger, more politicized bodies. Sometimes new functions have grown up within existing organizations, in the way that the OECD has taken a lead on tax alignment or the governance of AI. Sometimes new bodies are established, such as the Technology Bank, which was created to assist technology transfer to the developing world.

A typical example of newer global partnerships is the International Union for Conservation of Nature, which comprises 1,400 institutional members including nation states, NGOs, and scientific and business organizations, and provides analysis and ideas, some of which end up as conventions. Gavi, the vaccines alliance, is another example: created with the support of the Gates Foundation, it includes national governments and United Nations agencies on its board, but these remain in a minority. Its main task is to orchestrate knowledge. Another example is the Global Fund, which has spent nearly $50bn since 2002 in combating AIDS, TB and Malaria.[2]

Most relevant to STRINGS is the rise of bodies dedicated to orchestrating knowledge to help the world think and act, such as the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). These rarely have any formal executive power but influence decisions through mobilizing data and knowledge.

A good starting point for improving the global governance of R&D, and better aligning it with global goals, would be an equivalent for STI – a global platform observatory for science and technology (G-POST).

Such an observatory would be responsible for gathering and harmonizing data, making forecasts, and attempting to overcome the secrecy that surrounds R&D for military and intelligence purposes. It would track and analyse global patterns, and allow discussion of alternative possible orientations and portfolios for R&D in particular sectors and geographical contexts. It would need to work closely with the International Science Council, the International Network for Government Science Advice, OECD, UNESCO, as well as civil society, business, universities and other users of STI.

A circular model

Experience of observatories confirms that they work best if they operate in a circular model. Unlike a linear approach, which simply provides data and knowledge, a circular model recognizes that which facts are prioritized, and how they are communicated, needs to be influenced by the likely users of data and knowledge.

So, the primary role of a platform observatory might be to provide easily accessible source materials, including:

- A **website** that provides the best available data on R&D options, spending levels, locations, purposes and specific forms and directions for STI, in ways that are easy to use and interact with, including analyses by country, sector or technology cluster. As discussed in chapter 12, it should allow different stakeholders to appraise which STI directions and areas apply to particular challenges. The site could also provide comprehensive links to other validated sources, either on specific issues or at a regional and sectoral level.
- An **annual survey** to uncover key issues and emerging trends, along the lines of the Human Development Report, the World Development Report or the World Happiness Report.

These materials would be designed in cooperation with likely users and interested parties. An observatory could provide a living map of key issues, including:

- how R&D relates to global disease burdens
- the development of R&D capabilities in lower income countries
- the potential negative impacts of, and inequalities generated by, STI
- the development of different innovation pathways
- the national alignment between STI and the SDGs

Over time the aim would be to encompass coverage of both upstream and downstream funding – that is, technology applications and uses as well as research – and to branch out into social innovation, business model innovation and process innovation, which are increasingly important to society and the economy but are poorly captured in terms of data and largely ignored by innovation funders.

The platform observatory could be given formal advisory and reporting roles, for example, to the United Nations Secretary-General. Alternatively, it could sit within the structures of the United Nations Development Programme (UNDP). In either case, such an institution would not be expensive and could be funded in proportion to nations' R&D spend, initially perhaps by the G20.

Choices in creating the platform

There are choices to be made in the creation of any observatory platform, including the following:

- How much to emphasize 'supply push' or 'demand pull'. There is value in having accessible repositories of data or knowledge but more impact is likely to be achieved through close relationships with users, in the way, for example, that demand for knowledge about vaccines or Covid-19 treatments accelerated collaboration.
- Whether to aim at synthetic indices or rankings or to offer more open and plural approaches. The Human Development Index is an example of the first while the OECD's well-being measures are an example of a more flexible version.
- How much to organize data and knowledge using sectoral definitions or whether to focus on challenges, tasks and missions instead.
- How much to engage users, including interested and affected communities and citizens.
- Whether to start small and seek incremental growth or aim for a more ambitious start with support from a group like the G7 or G20.
- How far to evolve beyond an observatory into a genuine platform that convenes commercial, governmental and civil society interests and is open to public scrutiny, making it easier to debate and challenge established patterns of steering.

Constellations focusing on SDG priorities

The second level of proposed action is through **constellations** – partnerships and assemblies of key players in specific fields, gathering around key priorities such as energy, child malnutrition or water, and generating shared maps of funding allocations with the aim of avoiding duplication or tackling gaps. These constellations could bring together national bodies, major development funders, civil society and science – replicating the type of exercise undertaken by the STRINGS project.

Much of the work of existing global bodies involves such partnership and collaborative problem-solving. In some cases, these are formal partnerships involving capital; in others they are alliances or coalitions around specific issues such as malaria, access to water or gender equity. Many are meta-organizations that bring together other bodies. Some compete with each other, and some are driven by major philanthropists and largely bypass other global entities. Their tasks are often time-limited rather than permanent – for example, they might address intense phases of a problem such as conflict reconstruction, drought or famine, a refugee surge or a financial

Figure 11.1 / How global governance of research and development can support the SDGs

crisis. Most combine private funding (primarily philanthropic) and public money.

The STI equivalents could work mainly for a time-limited period to accelerate or galvanize research on key priorities. The principle would be open coordination rather than hierarchical control – making visible both needs and actions, and including actors across stakeholder groups, contexts, ethnicities and institutions in defining the key priorities.

Constellations around certain issues might need to be more permanent. Disability, for example – an issue that affects more than a billion people worldwide – is a prime candidate for a new constellation to coordinate research, development and commercialization. Global work on disability requires many things to be aligned: science and technology (to address needs like sight, hearing, mobility), promoting policies and new rights (including in the labour market), as well as ensuring that people with disabilities play a full role in shaping policies. It is a space where business could have as big a role to play as government, for example in accelerating R&D around new technologies for mobility.

Food is also a good example because of the range of existing bodies such as the Commission on Sustainable Agriculture Intensification, processes such as the International Assessment of Agricultural Knowledge, Science and Technology for Development, and gatherings such as the United Nations Food Summit. A formal constellation could open up debate about alternative pathways, including the merits of precision agriculture, GM seeds and insect growth regulators on the one hand, and agroecological methods such as rainwater harvesting adapted to local conditions on the other.

Such constellations could benefit from shared operating systems, including funders committing to open data principles (such as the 360-degree giving approach taken by many philanthropic funders, which makes it easy to aggregate funding and analyse by purpose and location).[3]

In general, such constellations work best if they focus on fields of action, challenges and missions rather than particular technologies. But sometimes these would need to be complemented with constellations which focus on families of technology, seeking out new applications. A current example is AI: shifting R&D on AI towards the SDG goals, after the long prioritization of military, intelligence and commercial priorities. This is a field with many individual projects, but relatively little strategic insight into alternative pathways, and little work on the underlying data sources. Another example is the use of collective intelligence (CI) methods. These are now being used by dozens of the UNDP Accelerator Labs to develop innovative ways of meeting the SDGs (including the combination of CI, AI, data and other tools). But so far they have had very little support from the main STI funders.[4]

3

Global pooled budgets

A next step from constellations would be a formal pooling of budgets. There is some history of doing this at scale. CGIAR (originally the Consultative Group for International Agricultural Research), for example, has operated a pooled budget since the 1960s, amounting to over US$500 million each year, and linking foundations including Rockefeller and Ford with major public donors. After playing an important role in the 'green revolution' of the 1960s, much of its work focused on the genetic development of crops, which sparked controversy.

Other examples include the Global Fund – which has mobilized around US$4 billion each year to support projects dealing with AIDS, TB and Malaria – and the Global Innovation Fund – a recent collaboration between the UK, Sweden and the US, involving foundations such as Omidyar and companies such as Unilever. Gavi and later COVAX have also enabled joint action by groups of donors and foundations.

These bodies are primarily accountable to their funders rather than the public or potential beneficiaries, and have been criticized for emphasizing the particular orientations for R&D favoured by these interests. One issue for the future would be how to ensure greater transparency and responsiveness to the groups they are intended to benefit.

But pooling of resources can greatly increase the impact of spending, and it is striking that it is missing in so many important areas – from gender equity to oceans – even though the sums involved in the examples above are relatively small compared to overall R&D.

There may be advantages in creating a menu of templates for such funds: providing model legal forms, model governance and decision-making structures, and protocols for the use of evidence and communication, for example. At present, each is bespoke, which means high transaction costs and unnecessary duplication.

4

Summits and conventions

A fourth proposal is to establish regular summits and conventions. Such events play a crucial role in creating communities of shared purpose and understanding, as well as in catalysing or provoking wider social deliberation over the steering of policy.

This is true of the COP series, G7 and G20 and others, which – for all their imperfections – contribute to an alignment of purpose. The failure to align STI with the SDGs is in part the result of a lack of places to discuss this issue. The OECD has its Global Science Forum[5] and UNESCO has its Global Observatory of Science, Technology and Innovation Policy Instruments[6] but neither feed into aligned decision-making. The same is true of gatherings like the STS forum[7] and more recently of the

Geneva Science and Diplomacy Anticipator (GESDA) which is focused on anticipating future science trends.

While there are many global gatherings around science and R&D, particularly academic gatherings such as the Society for Neuroscience (recent attendance of 30,000), European Society of Cardiology (32,000), and the American Chemical Society (15,000), there are no comparable meetings that connect to power, funding, policy and civil society, and none that look at R&D in the round. One option would be to combine an annual or biannual survey from the proposed global platform observatory with a gathering to debate the findings, key issues and gaps.

A more ambitious approach would build on the relative openness of the COP gatherings which have succeeded in bringing together civil society, business and scientists alongside governments. The aim would be to combine some of the flavour of civil society gatherings (like the World Social Forum which flourished briefly earlier this century) with the elite nature of gatherings like the World Economic Forum.

The way forward: inspiration, models and barriers

These options emanate from the STRINGS project but they also have a larger context. A useful thought experiment is to imagine that the United Nations was being invented in the 2020s rather than the 1940s.

Then the priorities included stopping interstate war, reshaping flows of finance and helping refugees. A United Nations being built now would place data and knowledge on as prominent a footing as finance, reflecting an economy in which the most valuable companies are now largely based on data and knowledge rather than finance or oil.

So, we would not just have a World Bank and an IMF but a global data agency, a network of 'what works' centres, and platforms for experimentation, all aimed at accelerating the achievement of the SDGs by better mobilizing the world's knowledge and better synthesizing it to make it useful.

The IPCC is an important example of what a more systematic global orchestration of knowledge could look like. It draws on the work of thousands of scientists and many computer models to provide the analytic underpinnings for global negotiations on climate change. Many of the more recently created bodies, including IPBES, have prioritized generating and sharing knowledge in order to influence decisions and have obvious relevance for R&D prioritization.

Systematic orchestration of data and knowledge is what big commercial platforms, from Google to Tencent and Amazon, already do, but they are focused on extracting profit from data and selling consumer goods rather than reaching goals for the public good. For now, there is no institution in the United Nations system with responsibility for these fields, which means initiatives are small-scale, fragmented and less impactful than they could be.

> 'Major changes in governance always look impossible and unlikely – until they happen. But once they have happened, they appear obvious and inevitable.'

Many initiatives are beginning, which could in time build up to a true global knowledge commons, so that within a generation it would be possible for the world to know, interpret and shape how it allocates scarce resources, including brainpower and computing power, to ensure that these are better allocated than the current system allows.

It is not hard to see the barriers. National governments are guided by many goals in shaping STI policies, from national glory to commercial competitive advantage. SDGs will always sit alongside other goals. But the experience of health shows that concerted global coordination and action is possible; coalitions can align the interests of business, NGOs and others; and some politicians can see why it is in their interest to reorient STI to the needs of their citizens.

This is why we should not be too cautious. Major changes in governance always look impossible and unlikely – until they happen. But once they have happened, they appear obvious and inevitable.

Notes

1. Mulgan, 2019.
2. www.theglobalfund.org/en
3. www.threesixtygiving.org
4. https://smartertogether.earth
5. https://www.oecd.org/sti/inno/global-science-forum.htm
6. https://en.unesco.org/go-spin
7. https://www.stsforum.org

> CHAPTER 12

Making use of STI mappings

Empowering stakeholders to select the relevant STI for SDGs

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Footnotes for this chapter are on page 130. A full list of references can be found on page 140.

OVERVIEW

- Existing mappings of publications and patents hide the diversity of ways that STI may lead to sustainable development.
- In contrast, the STRINGS approach provides a visualization of research landscapes, based on research areas, revealing a range of diverse research options related to one or more SDGs.
- These visualizations illuminate gaps, potential synergies, and current imbalances in STI investments.
- Our interactive visualization tool allows stakeholders to inspect research areas that are potentially related to a given SDG, and to develop their own mapping, according to their context and perspectives.
- Rather than a unique map of STIs for each SDG, there are a multiplicity of 'mappings' dependent on the choices made by stakeholders.
- The tool is based on the Web of Science, a mainstream publication database with uneven coverage. More comprehensive databases are needed to reflect research activities in different disciplines and in lower income countries.

Introduction: allowing for choice in the exploration of STI for the SDGs

One of the key insights of the STRINGS project is that a disparate range of science, technology and innovation (STI) activities may potentially contribute to a given sustainable development challenge, and that stakeholders hold diverse views about which STI directions should be pursued, according to their particular perspectives, values, needs or interests.

This diversity of options and perspectives presents a challenge for attempts to map STI activities to the Sustainable Development Goals (SDGs). While conventional mapping techniques work in scientific or technical fields, where differences in understandings are relatively small, they are problematic in the case of divergent understandings as when mapping STI activities to the SDGs. These differences in understanding are clear from the results of our Delphi study (chapter 7), as well as the range of STI pathways in the case studies (chapter 8).

It is clear that a consensus cannot be reached about the type of STI activity needed to achieve a given SDG or target. Neither should analysts aim to construct a consensus about the best or preferred STIs for achieving SDGs as this would fail to respect a key SDG value, namely cultural diversity and political autonomy, for example of indigenous people and ethnic minorities.[1] Instead, analysis should embrace the plurality of stakeholders' perspectives about the various research directions that may contribute to the SDGs.

In this chapter, therefore, we introduce our open, interactive visualization tool, together with a description of participatory processes. These tools and processes can empower stakeholders to explore and develop their own mappings of STI for SDGs, choosing those research areas which they perceive as appropriate for addressing SDGs according to their context, needs, values and aspirations.

A multiplicity of possible mappings of STI for SDGs

Previous attempts to map research efforts to the SDGs[2] take a dichotomous approach: some publications or projects are classified as contributing to an SDG, while others are classified as not contributing. These classifications are based on technical criteria, such as the presence of particular keywords associated with an SDG, or the similarity with a set of documents considered central to a specific SDG by experts.

In general, these maps or research landscapes are created by positioning publications on a two-dimensional visualization according to their similarity in citation patterns, disciplines or topics. The resulting maps and landscapes are thus contingent on inevitably subjective choices about the publication database used, the specific keywords selected, and the particular methods of grouping and positioning publications.

Choice of database

The first challenge is the comprehensiveness of the publication database that is used to map research. It is well known that mainstream bibliometric databases are skewed towards certain academic fields of study, dominant languages and richer countries.[3] As a result, social and applied sciences, along with research that is relevant to developing countries, are severely underrepresented.[4] Due to constraints in resources and time, the STRINGS project uses the Web of Science database. This is a major limitation of this study: future studies should aim to use more inclusive databases such as Lens.org or OpenAlex. To this end, we urge international bodies to support the creation of open information infrastructures that improve the coverage of research in middle- and low-income countries, in applied fields and in diverse languages.[5]

Procedures for connecting STI to the SDGs

A more intractable challenge is the reliance on particular procedures to characterize relations between the publications and the SDGs. In our case, the procedure is based on keywords associated with a given SDG. However, since SDGs are often not explicitly mentioned in scientific publications (perhaps because expert readers are expected to already know about, or not be concerned with, the potential applications of the research) the process of mapping projects or articles to the SDGs must be carried out through an interpretative process. Such a process is inevitably dependent on subjective understandings of research and the SDGs.

In some cases, there may be consensus about the value of research for achieving the SDGs. For example, most analysts would agree that research on malaria is important for achieving global health. However, in a number of SDG areas, such as SDG 2 (Zero hunger) or SDG 10 (Reduced inequalities), there are stark disagreements about the potential benefits of certain types of STI. Some stakeholders believe that genetically modified crops will help reduce hunger, for example, while others would argue that these approaches will impoverish small farmers.[6] Moreover, relatively little research explicitly mentions gender equality (SDG 5), despite the large amount of research into issues such as robotization, AI and transportation, whose application may have an impact on gender-based inequalities.

Figure 12.1 / Allowing for choice in the exploration of STI related to the SDGs

THE CHALLENGES

Previous attempts to map STI for the SDGs have produced dramatically different results due to different underlying perspectives and approaches:

CHOICE OF DATABASE

Most mainstream bibliometric databases are skewed towards academic fields of study, dominant languages and richer countries – meaning informal research in lower income countries is likely to be ignored.

CONNECTING STI TO THE SDGs

The mapping process is dependent on subjective understandings of research and the SDGs. This inevitably influences the resulting maps.

OUR APPROACH

Our interactive tool allows stakeholders to construct their own mapping that fits their circumstances.

DIVERSITY

After identifying all research areas potentially associated with a given SDG, stakeholders can pick which topics to prioritize.

ALIGNMENT

Users can then check whether the research portfolio for a given SDG is aligned with the most pressing needs.

PLURALITY

Our tool can be used by people in various contexts with a range of different perspectives.

Disparities between mapping studies

These differences in underlying perspectives and databases have surfaced in dramatic statistical disagreements between the findings of mapping exercises.[7] When comparing the papers related to SDGs retrieved by a Bergen University team with those retrieved by Elsevier's study, the Bergen team found astonishingly little overlap. For most SDGs, they found only around 25% to 35% agreement, as illustrated in Figure 12.2.

A consortium of universities for SDGs (Aurora) also found striking disparities between different keyword searches. For example, between the 2020 and the 2021 versions of Elsevier's mapping of SDG-related publications, there is less than 33% agreement for all SDGs except SDG 3 and 7, as shown in Figure 12.3. The comparison between Aurora's and Elsevier's search strategies yields even lower overlaps: they only agree on one or two out of every 10 publications they label as SDG-related.[8] Comparisons between the Elsevier, SIRIS, and Dimensions approaches and our own STRINGS approach have confirmed extremely large differences.[9]

These findings confirm that mappings of STI to SDGs are contingent on specific contexts, perspectives and understandings. In other words, the inconsistencies between mappings are due not only to methodological differences, but to different interpretations, implicit in the retrieval methods, of what type of STIs will help to achieve SDGs.

In summary, there is a multiplicity of possible meaningful mappings of STI for SDGs and the difference between mappings is significant. Under these conditions, rather than searching for a single 'best' mapping, we aim to provide a comprehensive SDG-related research landscape, allowing stakeholders to make choices about which parts of the landscape are relevant according to their own perspectives and contexts.[10]

Our approach: helping stakeholders develop their own mappings of SDG-related research

To accommodate stakeholders' varied understandings about which STI is most relevant to a particular SDG, our approach to mapping consists of three stages:

- Demonstrating the *diversity of STI research directions* for a given SDG.
- Examining *misalignments* in the distribution of publications.
- Understanding the *plurality of views* on research directions.

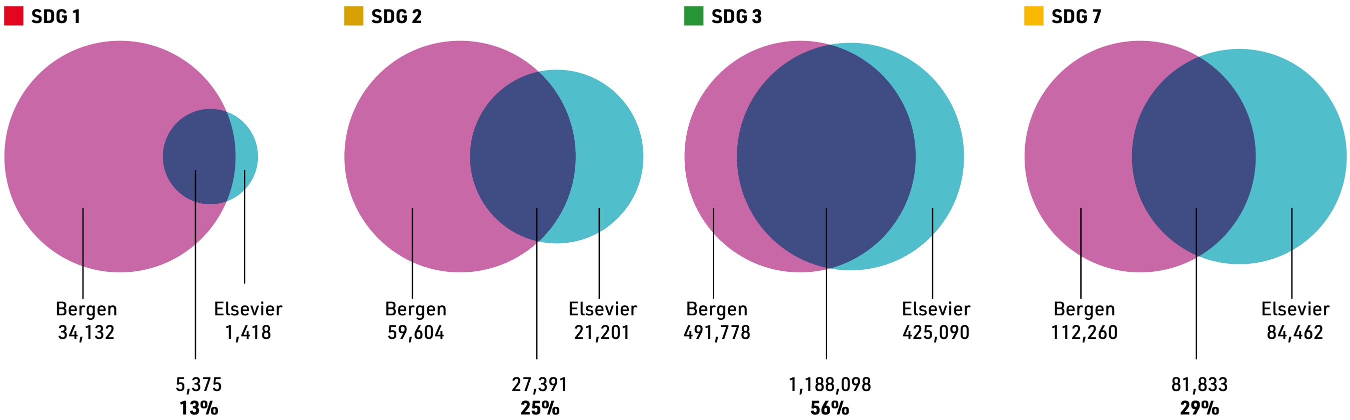
Diversity of research directions for a given SDG

In the first step, we aim to show the diversity of research options by identifying the research areas potentially associated with a given SDG (see Chapter 4). The research areas for a given SDG are visualized in a research landscape in which they are positioned according to their similarity, as illustrated in Figure 12.5.

The key innovation of our approach is to connect specific research areas (based on citation clusters), rather than individual publications, to SDGs. One advantage of this approach is that it assigns publications to an SDG not only based on the content of the publication, but also on the content of neighbouring publications. This aggregation makes the assignation statistically more robust.

A second advantage is that it provides a bird's eye view of the portfolio of topics potentially related to an SDG (in the same way as a farmer can look at the mix of crops in their property from a drone). This allows stakeholders to reflect on which of these topics should be prioritized and which are less relevant for them.

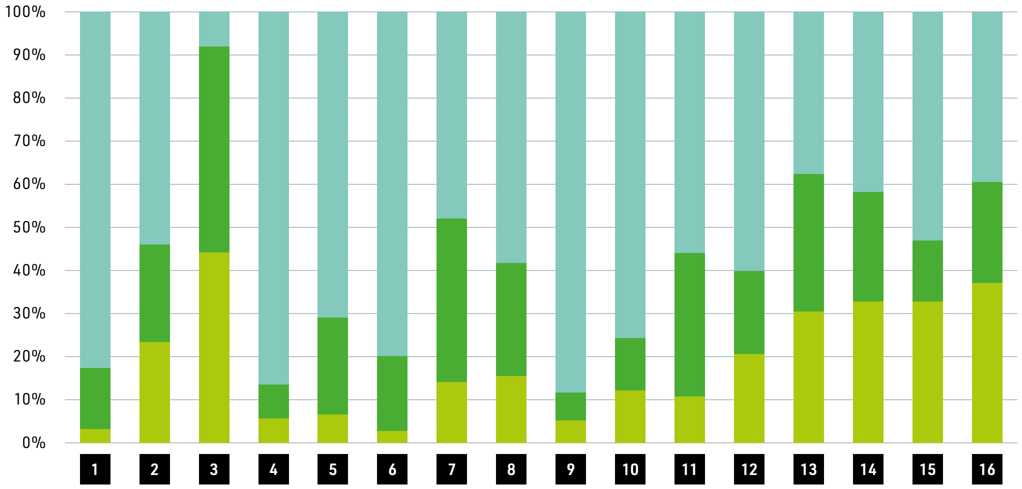
Figure 12.2 / Comparison between results of Bergen and Elsevier approaches to mapping SDG-related publications



> KEY
- Bergen study (publications identified as being related to this SDG)
- Overlap (the number of publications included in both studies)
- Elsevier study (publications identified as being related to this SDG)

Based on the Web of Science Core collection, 2015-2018. Source: Armitage et al. (2020).

Figure 12.3 / Comparison between results of two different Elsevier approaches (in 2020 and 2021) to mapping SDG-related publications



The dark green area shows the percentage of agreement (overlap) between the methods used in 2020 and 2021.

Source: Schmidt and Vanderfeesten (2021).

> KEY
- Elsevier 2020
- Overlap
- Elsevier 2021
- SDG number

> KEY: **Sustainable Development Goals**

SDG 1 No poverty
SDG 2 Zero hunger
SDG 3 Good health and well-being
SDG 4 Quality education
SDG 5 Gender equality
SDG 6 Clean water and sanitation
SDG 7 Affordable and clean energy
SDG 8 Decent work and economic growth
SDG 9 Industry, innovation and infrastructure
SDG 10 Reducing inequality
SDG 11 Sustainable cities and communities
SDG 12 Responsible consumption and production
SDG 13 Climate action
SDG 14 Life below water
SDG 15 Life on land
SDG 16 Peace, justice, and strong institutions
SDG 17 Partnerships for the Goals

The disadvantage is that it is difficult to label the contents of the clusters with keywords that are easy to understand by non-experts, in contrast to traditional disciplinary classifications, which are less precise but more user friendly.

In short the proposed approach goes beyond counting whether a particular organization or country has more or less publications relating to a certain SDG. Instead, the visualization of a portfolio of research areas enables an analysis of how to target specific goals by focusing efforts towards particular directions in the research landscape.

Examining misalignments in the distribution of publications

In a second step, we examine misalignments in research directions within an SDG. This type of analysis is important to check whether the whole research portfolio for a given SDG is indeed aligned with the most pressing needs or aspirations of a given population for that SDG (see Chapter 6).

SDG 3 (Good health and well-being) is useful to illustrate this approach. SDG 3 is the goal with by far the most related research, in both high- and low-income countries (see Chapter 4). However, as shown in Figure 12.4, many more publications relate to cancer, which affects relatively more people in rich countries, than to diseases such as malaria or tuberculosis or cardiovascular diseases which affect poorer populations (see Chapter 4).

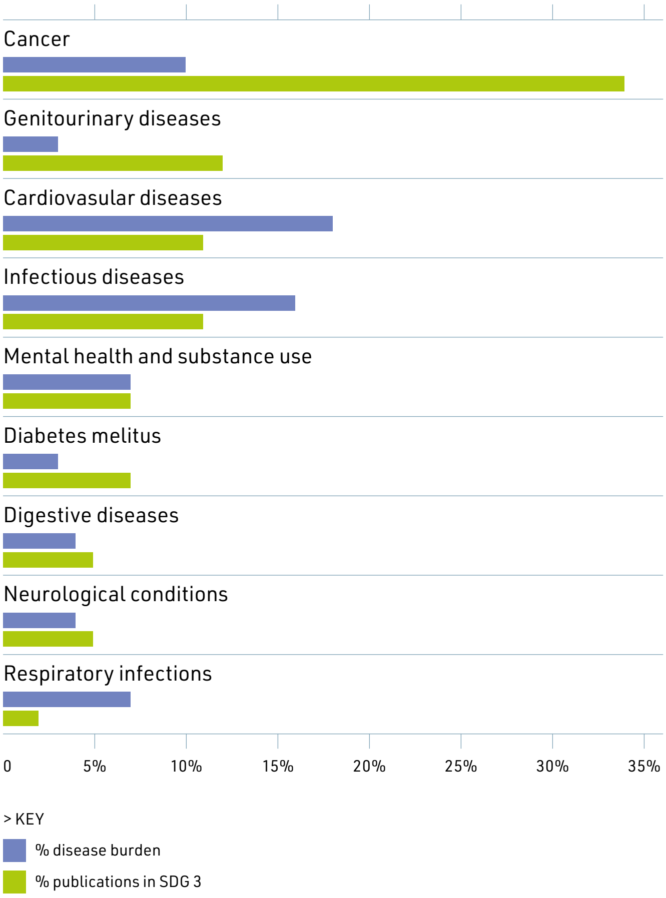
Provided with such information about the distribution of health research efforts in the SDG-research landscape, stakeholders may consider increasing their research into relatively understudied diseases that affect poor populations, and may choose to put less effort into fields such as some cancers, which are already highly funded in relation to their disease burden.

Similarly, the analysis of publication distributions may help stakeholders to consider which approaches (and therefore which solutions) to prioritize for a given problem.[11] For example, decisions about research for SDG 3 depend on the relative value accorded to prevention, care, treatment and diagnosis. The research areas relating to SDG 3 include three topics linked to Alzheimer's disease (which is relevant to target 4 of SDG 3: mental health). These topics comprise one large cluster on psychiatry and clinical neurology, one on the amyloid-beta proteins that cause Alzheimer's (basic biomedicine), and one smaller cluster focused on caregiving (gerontology).[12] While all three may be relevant to achieving the SDG, there are decisions to make: since there are no medium-term expectations of silver-bullet therapies for Alzheimer's, which of these three approaches deserves further support?

A plurality of views on research for the SDGs

To enable stakeholders to better prioritize among the diversity of research options related to SDGs, it is important to assess the potential benefits and harms to sustainable development of different types of research. For example, it is useful to compare the relative long-term benefits of therapeutic versus

Figure 12.4 / Percentage of disease burden in 2015 against percentage of disease publications in SDG3 in 2015-2019, for the world for the main disease groups.



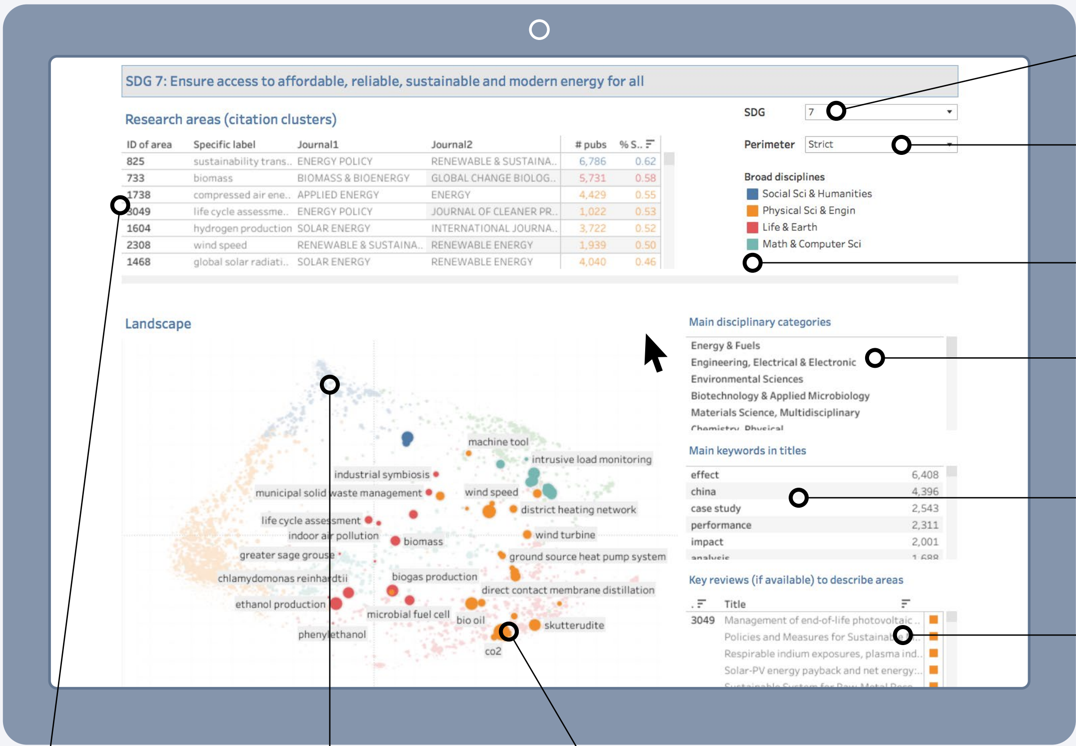
preventative approaches to mental health. This is not only technically difficult, but is also inevitably shaped by different perspectives on the value and impact of research.

Therefore, the STRINGS proposal is to be as transparent and flexible as possible about how topics (and associated research areas) are related to SDGs. We are developing visualization interfaces, such as the research landscape shown in Figure 12.5. These tools are designed to help stakeholders explore research areas and choose which ones they consider most relevant to each SDG, thus constructing their own mapping of STI for SDG – a mapping that fits their particular circumstances and preferences

As shown in Figure 12.5, the visualizations show research areas that are potentially relevant for each SDG. Currently, interactive functions allow users to explore the contents of each research area. We are making efforts to improve these platforms, but deeper expertise in visualization design and participatory methods is needed to further develop the interfaces and the contextual mapping processes. The research areas shown represent technical areas of expertise and may

Figure 12.5 / Interactive visualization of the research landscape for SDG 7 (Affordable and clean energy)

The STRINGS interactive tool enables users to create their own mapping of scientific research to the SDGs. Users can adjust settings to identify research areas that are potentially relevant for each SDG.



be challenging to interpret for non-experts. More user-friendly analytical tools will be needed to illuminate the relations between the needs and demands of social groups and specific research areas or other aspects of STI.

Given these complexities, a variety of transdisciplinary appraisal methods, combining analytical and interpretative as well as qualitative and quantitative approaches and capabilities, will be needed to empower users to make choices. The development of quantitative analytical tools needs to be intertwined with the development of social research methodologies for the inclusive engagement of diverse stakeholders in the use of these tools.[13]

While the approach proposed in this chapter relies on specific interfaces that are shaped by particular methodological choices and need some further development, we believe it offers an important way of ensuring that STI contributes to a plural and democratic pursuit of the SDGs.

Notes

1. Virtanen et al., 2020.
2. Jayabalasingham et al., 2019; Wastl et al., 2020.
3. Mongeon and Paul-Hus, 2015; Chavarro et al., 2018.
4. Vessuri et al., 2014; Rafols et al., 2015.
5. Vessuri et al., 2014.
6. Ely et al. 2014; Ruttan, 2015.
7. Armitage et al., 2020; Schmidt and Vanderfeesten, 2021.
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9. Purnell, P. J., 2022.
10. Rafols and Stirling, 2020.
11. Ciarli and Rafols, 2019.
12. Rafols, I., Yegros-Yegros, A., van de Klippe, W., and Willemse, T., 2022.
13. Rafols and Stirling, 2020.

> CHAPTER 13

Areas for policy action

Recommended interventions to address misalignments between STI and the SDGs

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Footnotes for this chapter are on page 139. A full list of references can be found on page 140.

OVERVIEW

We propose a transformation of research funding and support systems, to mobilize a diversity of pathways to address the SDGs.

We identify four main **areas for action**, with specific policy recommendations for research funders and policymakers:

1. Increase funding for SDG-related research and innovation, particularly in low-income countries
2. Devote more funding to research that addresses underlying social inequalities, social innovations and informal research, in combination with technical solutions
3. Improve alignment between countries' SDG priorities and their STI portfolios
4. Adopt a more holistic approach to research evaluation, with indicators and data that relate to a range of desired inputs, outcomes and impacts

Introduction

This chapter draws from the findings in Section 2 to outline the main challenges and opportunities for STI policy to better contribute to sustainable development. We identify four overarching **areas for action**, each with specific recommended policy shifts for policymakers, researchers and funders to meet SDG-related challenges.

Our recommendations build on and refine recent academic and policy debates which promote shifting the focus of R&D expenditure from mainly supporting economic and productivity growth towards addressing sustainable development.[1]

Calls for change include: revising the use of indicators to appraise the success of investments in research and innovation;[2] increasing the involvement of diverse researchers and other stakeholders in setting STI funding and policy priorities;[3] increasing funding for interdisciplinary and transdisciplinary research;[4] and paying attention to evolving priorities by maintaining an open portfolio of research directions.[5]

These shifts require a revision of funding instruments and their governance, as discussed in Chapter 11. New systems of monitoring and evaluation, supported by ambitious data-collection, are also needed, to enable funders and policymakers to take account of diverse and plural STI directions and of different ways of appraising successes and failures.

> '... shifting the focus of R&D expenditure from mainly supporting economic and productivity growth towards addressing sustainable development.'

Specific policies will naturally differ across contexts. As discussed in Chapter 10, policy approaches that recognize diversity are necessary to address the multiple challenges related to the SDGs.

Most of our recommendations are aimed at research funders, aid agencies and philanthropies. However, research funding systems can undergo these radical transformations only if the broader STI policy community and innovation system – from individual researchers to private companies, higher education organizations and financial institutions[6] – also embrace the changes.

AREA FOR ACTION #1

Increase funding for SDG-related research, particularly involving LICs

Challenge 1: Research and innovation are largely unrelated to the SDGs, especially in richer countries

Our research reveals a global misalignment between the SDGs and research and innovation priorities. Between 60% and 80% of publications authored in high-income countries (HICs) and upper-middle income countries (UMICs)[7] in the Web of Science (WoS) between 2015-2019 are unrelated to the priorities and challenges of the SDGs. This proportion falls to 20-40% in low-income countries (LICs),[8] but these countries account for only 0.2% of the research output published globally.

The figures are even more dramatic if we consider patented inventions, which can be taken as a proxy for innovative activity. In HICs and UMICs, 97% and 98% of inventions respectively are unrelated to SDGs, falling to 91% in LICs.[9] Again, the contribution of LICs and lower-middle income countries (LMICs) is minimal, at just 2%.

Challenge 2: Research funding is concentrated in relatively few organizations in HICs

LICs face larger SDG challenges than most other countries.[10] However, it is HICs and UMICs that account for the vast majority of all WoS publications (93%) and patents (98%), and very few of these involve partnerships with lower-income countries. The proportion of publications and inventions produced in collaboration between HICs or UMCs and LICs is below 0.5%.[11]

While this marginal participation of a large part of the world's population is in part due to the WoS focus on 'excellent' journals in the English language,[12] it also reveals the international inequalities governing research funding. STI priorities are driven overwhelmingly by research organizations in HICs and a handful of large UMICs. The negligible involvement of researchers from LMICs and LICs limits the impact of research on the users and contexts that need it most.[13]

The limited participation of researchers and inventors from LICs and LMICs also undermines the creation of research and innovation capabilities that could enhance all components of these countries' research and innovation systems.[14] Research and innovation capabilities have certainly been growing and evolving in LICs and LMICs.[15] However, we were unable to fully capture these capabilities in our analysis due to lack of data.[16] More data and research are needed to better measure research and innovation capabilities in LICs beyond those captured by the WoS and patents.

Our findings also show that, within countries, a significant share of WoS SDG-related research is conducted by a few large organizations. While economies of scale may benefit research productivity, such concentration makes it harder to encompass multiple perspectives and explore diverse STI pathways (as recommended in Chapter 10). This is particularly the case if representation within research organizations is biased in terms of gender or ethnicity.[17]

Figure 13.1 / Area for action #1: Summary of recommendations

RECOMMENDED POLICY SHIFTS

1 INCREASE FUNDING FOR SDG-RELATED RESEARCH, PARTICULARLY INVOLVING LOWER-INCOME COUNTRIES

FOCUS ON SDG CHALLENGES
Fund more research and innovation that directly addresses SDG-related issues

ACCOUNT FOR DIVERSITY
Involve a wide range of actors in research funding decisions

INCLUSION OF LOW INCOME COUNTRIES
Increase the funding and inclusion of diverse research institutes from LICs

EQUITABLE RESEARCH PARTNERSHIPS
Ensure that international collaborative research is equitable

AREA FOR ACTION #1

Recommended policy shifts

Fund more research and innovation that directly addresses SDG-related issues

Our findings indicate a need for funders and policymakers in HICs and UMICs to steer STI funding towards SDG-related challenges. This requires decisions about what types of research and innovation are related to the SDGs (Chapter 12) and which to prioritize among complex, contrasting and synergic directions. Defining such priorities is a crucial part of ensuring that STI contributes to the SDGs.

Involve a wide range of actors in research funding decisions

The recent re-emergence of mission-oriented STI policies[18] may help steer STI funding towards broad SDG challenges.[19] However, such top-down missions tend to privilege a single solution to very complex problems.[20] Funders and policymakers should consider the relevant contexts and the plural understandings about SDG priorities and how to address them.

To better align research funding with the complex and diverse SDG challenges, public and private R&D funders and policymakers should:

- involve a more distributed set of actors in the design, implementation and evaluation of research funding[21]
- ensure that data, monitoring and impact evaluations underpin decisions and approaches to reorienting and steering STI
- revisit consultative and evaluation processes regularly to keep up-to-date with evidence and challenges

We discuss some concrete options for addressing these points in Chapters 10 and 11.

Of course, consultation alone is not enough if it does not influence the prioritization of research funding. In some contexts, historically entrenched funding, disciplinary priorities and the interests of public and private organizations may suppress attempts to steer funding to address the societal challenges of under-represented groups.[22] For example, the European Commission (EC) involved citizens in the development of its Horizon Europe funding programme.[23] However, this participatory process seems not to have created a greater diversity of STI pathways to address societal challenges.[24] Compared with earlier EC funding programmes, it appears to have led to only a small improvement in aligning research funding with diverse societal values.[25]

By including LIC researchers and stakeholders in their advisory and management committees, policy and funding agencies can ensure that the views of plural stakeholders are considered in the planning, definition and evaluation of research agendas. Such broad-based participation tends to lead to research with stronger impact,[26] and can open up the practice of science by increasing transparency. This, in turn, may help government bodies and others to steer STI pathways towards SDG priorities (Chapter 11).

Increase the funding and inclusion of diverse research institutes from LICs

Since LICs focus most of their research on SDG-related issues, increasing research funding in these countries would directly boost research related to the SDGs. It could also improve capabilities to address the SDGs where they are most needed.

Therefore, national and international funding frameworks should focus on supporting SDG-related research that involves a leading role for research organizations based in LICs. The worldwide Think Tank initiative[27] and the DELTAS programmes in Africa[28] are examples of how the involvement of LIC organizations in leading roles can help to create research and innovation capabilities beyond academia.

Ensure that international collaborative research is equitable

Funders and donors should ensure that collaborative projects are based on equitable partnerships.[29] It is important that LIC partners are not exclusively data providers,[30] that decisions are taken collaboratively, and that LIC researchers can access data that is currently prohibitively expensive.[31] Such equitable collaborations may require investment in capabilities and capacities, and this investment should be integrated and valued as part of funded research projects.

Equitable collaborations can also help funders, donors and researchers in HICs and UMICs to better understand existing research portfolios, priorities and capabilities in LICs, thereby increasing the effectiveness of funding and avoiding duplications.

Our analysis of Chagas-related publications revealed that international collaborations, especially between HICs and non-HICs, are particularly important in steering research towards the SDGs. Collaborations between HICs and non-HICs constitute 26% of SGD-related research on Chagas disease, compared with just 18% of non-SDG-related research on Chagas. Moreover, when HIC research about Chagas involved collaborations with non-HIC authors, it was more likely to be related to the relevant SDGs (3, 5, 11 and 15).

Science policy initiatives and research funders have been supporting the development of research infrastructure and capabilities in UMICs and LMICs for many years, with the aim of creating more equal partnerships. A synthesis of evidence related to those efforts could help to inform future policy and investment.

Similarly, some organizations in HICs are already pursuing funding models that prioritize LIC-based research and amplify LIC researchers' and stakeholders' views about STI priorities. These include the Swedish International Development Agency; the International Development Research Centre (IDRC) of Canada, which restricts the amount of money spent on researchers in HICs; and the German International Climate Initiative, which aims to spend at least 60% of its funding in LICs. The UK's Global Challenge Research Fund also committed to building new and more equitable partnerships. However, an early evaluation concluded that its research agendas were still dominated by researchers from HICs.[32]

An example of LICs prioritizing LIC-based research is the Accelerating Excellence in Science in Africa initiative, which committed to 'shifting the centre of gravity' for science to Africa. It was established jointly by the African Academy of Sciences and the African Union Development Agency, in partnership with funding agencies such as the Bill and Melinda Gates Foundation and the UK's Wellcome Trust. Although this initiative has run into difficulties, the concept behind its creation was powerful.

The Forum for Agricultural Research in Africa and the Asia Pacific Association of Agricultural Research Institutions both foster collaborative activities between LICs on knowledge exchange, knowledge management and policy advocacy. However, neither organisation promotes much research collaboration.

AREA FOR ACTION #2

Increase funding of research into underlying issues of deprivation, inequalities and conflict

Challenge 1: Research on underlying issues of deprivation, inequalities and conflict is underfunded

Underlying social issues that are central to SDG-related challenges include:

- inequalities within and among countries (linked to SDG 10)
- gender inequality (SDG 5)
- conflict, injustice and weak institutions (SDG 16)
- poor-quality education (SDG 4).

These areas attract a low and relatively slow-growing share[33] of research publications in the WoS, less funding and fewer international collaborations than average. However, there is evidence that research on these topics has a stronger influence on policy and society than other areas of research.[34] While research and innovation tend to focus on more technical solutions, social innovations are also needed to address the SDGs.

The discrepancy in research funding may be because different challenges need different amounts of research. Research related to societal issues may also be more common in literature not covered in the WoS. However, the shrinking support for research on deeply rooted inequalities – compared to, for example, energy (SDG 7) or economic growth (SDG 8) – is likely to be a major constraint to addressing complex priorities across all SDGs.

Challenge 2: A lack of connection between social and technical research

Crucially, research related to issues of deprivation, inequalities and conflict is isolated from research related to SDGs focused on the environment, infrastructure and growth.[35] Not only does this compound the above challenge, but it also highlights a serious disjuncture between STI quests for infrastructure, growth and environmental integrity on the one hand and the imperatives of poverty eradication, inclusion and peace on the other. This situation is at odds with the multiple recommendations that a more holistic approach, combining social and technical STI, is needed to address the SDGs.[36]

Our findings show, for example, that research related to SDGs 16 (Peace, justice and strong institutions) is disconnected from research related to SDGs 14 (Life below water) and 15 (Life on land),[37] despite the well-known connections between conflicts and access to natural resources. Indeed, our case study on fisheries in the Lake Victoria region (Chapter 2.3) demonstrates how the governance of fishing and the alternative pathways for improving access to fish relate to long-standing conflicts in the region.[38] Similarly, research on SDGs 4 (Quality education) and 16 (Peace, justice and strong institutions) is weakly connected with research on SDG 3 (Good health)[39] despite the importance of governance and education in addressing neglected diseases such as Chagas.[40]

Challenge 3: The importance of social innovations and informal research organizations in addressing the SDGs

Social factors are important in addressing the whole range of SDGs, including environment and infrastructure-related SDGs. In our global survey (Chapter 7), when asked about the STIs that are likely to contribute to specific SDG targets, stakeholders pointed to social, policy and grassroots innovations more than to physical technologies. For instance, social justice, increasing access to education, changing consumers' behaviour, public health, controls on invasive species, and affordable housing were among the highest-rated innovations across all SDGs, alongside renewable and solar energy. Despite this high prioritization, these topics form a marginal share of published research and do not appear among patented inventions.

Moreover, STI pathways to address SDG priorities are not always produced in formal research organizations. Our Indian case study[41] illustrates how STI pathways can be based around 'indigenous' or 'traditional' sciences and techniques. Although these STI pathways are difficult to capture with standard data, they must be taken seriously, considering the rich diversity of such pathways around the world and the importance given to grassroots and social innovations in our global survey.

Figure 13.2 / Area for action #2: Summary of recommendations

RECOMMENDED POLICY SHIFTS

2 — INCREASE FUNDING OF RESEARCH INTO UNDERLYING ISSUES OF DEPRIVATION, INEQUALITIES AND CONFLICT

FOCUS ON SOCIAL SCIENCES
Acknowledge the relevance of social, historical, political and economic issues to all SDG-related research

INVESTIGATE SYNERGIES AND TENSIONS
Focus on research areas that connect to several SDGs

INTER- AND TRANSDISCIPLINARY RESEARCH
Public research funders should lead investment in interdisciplinary and transdisciplinary research

AREA FOR ACTION #2

Recommended policy shifts

Acknowledge the relevance of social, historical, political and economic issues to all SDG-related research

STI policies should put social science and humanities research on deprivation, inequalities, conflicts and education at the core of funding initiatives. Such a focus will enable a greater understanding of how these issues are related to the full range of SDGs.

Social sciences research on these issues and their impact on the SDGs can be more contentious and harder to measure than, for instance, research on health technologies or renewable energy technologies. The impact of social science research on SDG targets related to deprivation, inequality, conflict and education is more difficult to attribute to specific projects[42] than is the case for health research, for example.[43] However, funders and researchers should not shy away from investing in research on these fundamental issues. As we recommend below, a more multidimensional approach to STI evaluation could help.

Focus on research areas that connect to several SDGs

Substantially more research is needed to better understand the synergies and tensions between the SDGs. Our research shows that only a few research areas are relevant to several SDGs.[44] For example, one large research area of more than 9,000 publications on environmental issues and economic development is related to SDGs 12 (Responsible consumption and production) and 13 (Climate action) as well as to SDGs 7 (Affordable and clean energy), 8 (Decent work and economic growth) and 9 (Industry, innovation and infrastructure). A smaller research area of around 1,700 publications that address topics related to food insecurity is related to SDGs 1 (No poverty), 2 (Zero hunger), 3 (Good health and well-being) and SDG 5 (Gender equality). These are highly interdisciplinary research areas, including research from the social sciences and humanities, physical sciences and engineering, life and health sciences, computer science and mathematics.

Funders may wish to learn from these areas and promote more challenge-led, rather than disciplinary-led, research to help understand synergies and tensions between SDGs. Beyond those few research areas that are relevant to several

SDGs, funders should fund more research that explicitly investigates tensions and synergies between different aspects of sustainability. It is especially important to connect research on deep-seated issues of deprivation, inequalities and conflict with research on more technical solutions.[45] More research is needed to understand, for example, how new technologies interact with complex societal, political and historical issues.

Public research funders should lead investment in interdisciplinary and transdisciplinary research

Research funders and science policymakers need to take seriously the production of knowledge in multiple arenas beyond formal science and technology.[46] Social innovations, 'indigenous' sciences and traditional techniques currently struggle to attract public funding and other support.

Greater support is also needed for interdisciplinary and transdisciplinary research, which could improve the understanding of synergies and tensions between socioeconomic, environmental and infrastructure-related SDGs. For example, in our case study on Chagas disease,[47] the bibliometric analysis shows that interdisciplinary research helps to steer research towards the SDGs. Open science practices, including the participation of a diverse set of actors in research production, also help to meet societal needs.

Beyond research, we need more funding to understand the impacts of translating and implementing research findings in specific contexts.[48] For example, narrowly focused biomedical health research alone is unlikely to solve health issues in LICs. To facilitate the implementation of biomedical science, research in the humanities, social sciences and public policy will also be needed. In the case of Chagas disease, for example, research into public policies and institutions (SDG 16), sustainable cities and communities (SDG 11) and education (SDG 4) are all relevant to tackling the disease, complementing research more directly related to health (SDG 3).[49]

> 'Greater support is needed for inter- and transdisciplinary research, which could improve the understanding of synergies and tensions between SDGs'

Interdisciplinary and transdisciplinary research projects can be difficult to design, conduct and assess but there is a clear need for STI policies to support substantially bolder efforts in this direction.[50] An important move would be to increase the active presence of diverse stakeholders in research projects. This should include not just academic disciplines but also representatives from across policy, industry and civil society. Examples include marginalized knowledge producers such as small farmers, forest people and water conservationists.

One option would be to complement formal research funding agencies with agencies that actively support informal research partnerships, including between researchers and social innovators. Few countries currently have agencies that promote practical and implementation research and related capabilities in the charitable and informal sectors.

Funding and creating spaces for interdisciplinary exchange, either within universities or with other actors such as funding or policy agencies, would also help promote this type of research. Chapter 11 provides examples of how this could be facilitated globally and locally.

AREA FOR ACTION #3

Address the misalignments between STI portfolios and SDG priorities

Challenge 1: Historical and ingrained patterns of funding

We found that countries' research priorities align with their SDG priorities for only four of the SDGs: SDG 1 (No poverty), SDG 2 (Zero hunger), SDG 3 (Good health and well-being), and SDG 6 (Clean water and sanitation).[51] However, these prioritizations seem to be driven by historical patterns of funding development research, rather than by SDG challenges themselves.

Challenge 2: LICs and LMICs need more funding to build their own research capabilities

While most SDG challenges are worse in LICs, only a tiny amount of SDG-related research takes place in those regions.[52,53] This means research users in LICs rely on research carried out elsewhere, which is likely to be less relevant to their contexts. An example is the dominant focus of global health research on diseases that cause a burden mainly to HICs rather than LICs.[54] The lack of SDG-related research in LICs is problematic since research is one of the key ways of creating capabilities to address SDG-related issues.[55]

Challenge 3: STI pathways differ in their alignment with different SDGs and targets

The STI pathways that become mainstream are not necessarily in the best position to address the diversity of SDG-related issues. For example, in our Indian case study,[56] the dominant pathway of breeding new rice varieties privileges input-intensive agriculture, thereby adversely affecting agrobiodiversity (relevant to SDG 2) and making agriculture less sustainable (SDG 12). The alternative pathway of in-situ seed conservation has positive impacts in both these SDG areas. However, it is not supported by public research funding because academic researchers consider that the dominant pathway leads to higher yields, thus achieving the target of doubling agricultural productivity (SDG 2).

AREA FOR ACTION #3

Recommended policy shifts

Research prioritization should be more responsive to national and local challenges

Countries and regions should regularly review how they prioritize research funding, in order to support shifting local and national SDG priorities.

Funding portfolios should be revised frequently, based on consultations across different disciplines and sectors of society. LIC researchers and users should be involved more consistently in decisions about funding research into SDG-related issues in their countries and regions. Otherwise, there is a risk of imposing research directions and innovation pathways that are driven by countries and organizations with limited understanding of local challenges.

Funding research into local challenges, in consultation with stakeholders, is also essential to create research capabilities. Ensuring strong research skills and opportunities in academia and beyond – for example, among doctors, public administrators or farmers – can help to make STI more effective and relevant.

Open and plural decision-making is needed to develop multidirectional funding portfolios

The diversity of SDG-related issues and STI pathways requires a diversity of research and innovation directions.[57] Research funding should support a wide array of different subjects, approaches and directions.

Funding programmes should prioritize diversification and avoid closing down pathways that may be important for addressing social and economic challenges.[58] A portfolio approach can be deployed to maintain a range of projects or interventions, each looking at a different dimension that is relevant to particular beneficiaries.[59] The portfolio approach may also involve funding a variety of projects across a continuum from radical to incremental innovation.[60]

Funders can use participatory processes, combined with evaluation and monitoring, to ensure that citizens' plural perspectives are taken into account and to prevent STI pathways, that are relevant to marignalized social groups, from being closed down.[61] It is important to involve plural stakeholders, especially research users and civil society organizations, in setting research priorities and criteria to evaluate research projects.[62] Such participation is also needed in the process of designing research funding, so that calls for proposals are shaped by plural perspectives.[63]

Figure 13.3 / Area for action #3: Summary of recommendations

RECOMMENDED POLICY SHIFTS

3 ADDRESS THE MISALIGNMENTS BETWEEN STI PORTFOLIOS AND SDG PRIORITIES

RELEVANCE AND DIRECTION
Research prioritization should be more responsive to national and local challenges

DIVERSE PERSPECTIVES AND PORTFOLIOS
Open and plural decision-making is needed to develop multidirectional funding portfolios

AREA FOR ACTION #4

Adopt a more holistic approach to research evaluation and data-collection

Challenge 1: The dominant evaluation systems hinder research that is relevant to the SDGs

Traditional research evaluation (which tends to equate excellence and research productivity with high-profile publications) hinders the development of interdisciplinary research, which is likely to have a stronger impact on the SDGs than other types of research.[64]

For example, several stakeholders view research related to SDGs 4 and 16 as important in tackling Chagas disease. However very little medical research is carried out in these areas,[65] as the research evaluation system does not reward medical researchers for considering educational and governance implications.

Changing the evaluation system to reward social impact as well as scientific excellence might steer research towards the complex social issues, such as deprivation, inequalities and governance, that are key to addressing technical challenges.

Challenge 2: Available data provide a biased picture of STI activities

Most evaluation of STI investments is based on bibliometric indicators produced using research outputs such as publications and patents.[66] Yet these are only two of many forms in which new knowledge may manifest itself (as discussed in Chapters 4, 5 and 12). Moreover, standard repositories such as the WoS include mainly English language publications. Thus, using standard bibliometric indicators provides an incorrect and incomplete picture of the research and innovation activities in lower-income and less formal settings.[67] It discounts many of the social, policy and grassroots innovations that stakeholders and researchers themselves consider so relevant to achieving the SDGs (Chapter 7).

The same limitations apply to our own analysis. Our mapping of global STI covers only those areas where we could access data (publications and patents). To better understand the changes needed to achieve the full potential of STI to meet the SDGs, we therefore combined our analysis of STI outputs with a global survey and three in-depth case studies.

AREA FOR ACTION #4

Recommended policy shifts

A more multidimensional approach to the evaluation of public STI

There is a need to broaden the current metrics-based approach to assessing research in order to promote more research on the underlying issues of deprivation, inequalities and conflict, and to increase the recognition of social innovations, different forms of knowledge, and the role of users. This does not mean compromising the quality of research. Our research indicates that SDG-related research on issues of deprivation, inequalities and conflict is as excellent as the average research in the WoS, as measured using standard bibliometric metrics.[69]

Nevertheless, funders need research evaluation measures that promote and value a diversity of research outputs and activities that may not fit the traditional definition of 'excellent' research. Evaluation should consider positive and negative impacts on society as perceived by different stakeholders. The key is to use a multidimensional approach, such as the RQ+,[70] which promotes several different evaluation approaches, rather than solely focusing on disciplinary excellence.

Moving away from traditional forms of evaluation requires a greater effort in data-collection, but is also likely to deliver development research that has a stronger impact on society.[71] Monitoring, evaluation and learning techniques have evolved rapidly and there is a growing body of assessment literature to inform approaches that consider plural understandings of diverse research pathways.[72]

We propose two practical examples for developing such measures in this report. In Chapter 6 we measure and appraise countries' research specializations in relation to their SDG challenges, using data on academic publications and SDG indicators. In Chapter 9, we appraise different STI pathways to address SDG-related challenges in specific contexts using multi-criteria mapping.

Funding agencies need to base their decisions on thorough evaluations, which involve the collection of detailed data and case studies, to better evaluate the impact of different STI pathways on the SDGs. Many research funders are beginning to adopt more comprehensive and finer-grained evaluations. Some, including UKRI and IDRC, are seeking to enhance the role of users, brokers and intermediaries in their research funding portfolios. This may facilitate the engagement of plural stakeholder groups with a range of perspectives on how STI can best contribute to the SDGs. Other funding agencies are developing innovative ex-ante approaches to inform research funding in light of the need to address societal goals. The Norwegian Research Council,[73] for example, recently undertook a consultative exercise, which included a foresight and futures component, to underpin its research strategy. This approach has the advantage of directly addressing the need to break from old patterns and pathways.

Research funders and policymakers need to engage more critically in analysing the relationships between research outputs and SDG outcomes. This can work better if we have decentralized research and funding institutions that allow stakeholders to engage more frequently. In Chapter 11 we provide a few concrete examples.

Invest in collecting more inclusive STI data

To avoid undue influence from HIC priorities, funders should give greater attention to research that is of local interest, published in languages other than English, and available in outlets that are accessible to research users and more open than academic publications and patents.

It is also vital to take advantage of the enormous advances in producing, harvesting and analysing unstructured data to fund the collection and use of data about forms of STI other than publications and patents.

In Chapter 12, we present a tool that enables stakeholders to develop their own mapping of SDG-related research, while Chapter 11 proposes ways for international bodies to collect and monitor data on STI.

Vital to the success of all our recommendations is the engagement of civil society actors working on informal and small-scale research and innovation efforts across the globe.

Figure 13.4 / Area for action #4: Summary of recommendations

RECOMMENDED POLICY SHIFTS

4 — ADOPT A MORE HOLISTIC APPROACH TO RESEARCH EVALUATION AND DATA-COLLECTION

MULTIDIMENSIONAL EVALUATION
Adopt a more multidimensional approach to the evaluation of public STI

OPEN AND INCLUSIVE DATA
Invest in collecting more inclusive STI data

Notes

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Just doing more R&D will not contribute to achieving the SDGs. We need more open and inclusive approaches to define STI priorities, in order to address the current misalignments with the goals. This is vital if we are to achieve our SDG targets and build a better, more sustainable world.

We need to start changing direction...

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