RESEARCH ARTICLE

Global UN 2030 agenda: How can Science, Technology and Innovation accelerate the achievement of Sustainable Development Goals for All?

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Abstract

The adoption of 17 sustainable development goals (SDGs) with 167 targets by the United Nations member states in 2015 emphasizes the critical role of science, technology and innovation (STI) in addressing sustainability challenges, including poverty, hunger, health, employment, climate change and energy. However, STI plays a limited role in the context of the global agenda of 2030 and for achieving SDGs in low- and middle-income countries. The perspectives of relevant stakeholder groups (i.e., policymakers, academia, donors, private sector, and non-governmental organizations) were assessed through an international survey on the role of STI in tackling SDG challenges in three main themes: agriculture, health, energy, and environment. Our findings reveal that human resource capacity on STI is still fragile in many developing countries, including some middle-income economies, suggesting that to achieve Sustainable Development Goals (SDGs) 1, 2, 3, 7, and 13, it is necessary to strengthen the educational system, increase investment in research and development programs, implement staff retention policies, foster collaboration, and provide adequate infrastructure and expertise for the required skills and competencies to promote cooperation in science, technology, and innovation (STI).

OPEN ACCESS

Citation: Adenle AA, De Steur H, Mwongera C, Rola-Rubzen F, de Barcellos MD, Vivanco DF, et al. (2023) Global UN 2030 agenda: How can Science, Technology and Innovation accelerate the achievement of Sustainable Development Goals for All? PLOS Sustain Transform 2(10): e0000085. https://doi.org/10.1371/journal.pstr.0000085

Editor: Hélder Spínola, University of Madeira, PORTUGAL

Received: June 8, 2023

Accepted: October 6, 2023

Published: October 30, 2023

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: https://doi.org/10.1371/journal.pstr.0000085

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Funding: The authors received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist.

Author summary

STI will play a critical role in achieving the sustainable development agenda such as the SDGs. Achieving the SDGs requires a strong national innovation system that encourages the implementation of an STI framework at the heart of government policy, and this entails building a comprehensive and robust STI system based on understanding the interaction between actors and the dynamics of STI governance. However, numerous countries worldwide are struggling to devise new STI policies that can effectively tackle the unique challenges posed by SDGs. Based on the perspectives of various stakeholders, we highlight the issues surrounding STI's role in tackling some SDG challenges. We present a framework for STI cooperation for the SDGs focusing on four dimensions: national planning, resource and capacity building, engagement and partnerships, and access to innovation to deal with the challenges and issues in incorporating STIs into achieving the SDGs.

Introduction

In 2015, the United Nations (UN) adopted a set of 17 Sustainable Development Goals (SDGs), including goals to address poverty, hunger, health, employment, the environment, and energy [1]. The SDGs emphasize the organizational operationalization and integration of sustainability and, therefore, address the current and forthcoming stakeholder needs. Hence, ensuring a better and sustainable future for all, balancing the economic, social, and environmental development [2]. Science, technology, and innovation (STI) are critical to achieving most SDGs, but successfully delivering STI solutions depends on overcoming longstanding challenges. Given the urgent need to address sustainability challenges within SDGs, new STI policies are required to tackle climate change, strengthen food systems, boost economic resilience, and sustain long-term growth, especially in low- and middle-income countries. Contributing to the effective formulation and implementation of STI is critical in this respect. A substantial body of literature exists linking STI's critical role in society's prosperity and well-being [3–7]. The importance of accelerating STI delivery to achieve SDGs has been highlighted by policymakers and in the literature as a crucial issue in the wake of the economic, health, and social consequences of the COVID-19 pandemic [8,9].

Over the years, STI policies, which are one of the critical elements for the implementation of the sustainable development agenda, have become more complex partly due to diverse factors that intervene in the process [7,10,11]. The dynamics of multi-stakeholder partnerships for implementing STI policies at the global level raise fundamental issues around the innovation system and its approach in national and regional governments. As a result, it reinforces the need to recognize the network of organizations, actors, and individuals and the rules for introducing, disseminating, and exploiting existing or new technology and knowledge [12,13]. This raises concerns about how various actors and institutions can work together to promote the acquisition and diffusion of innovation systems in terms of knowledge and ideas that will help determine the direction, scale, and successful implementation of SDGs. For example, private sector, consumers, academia, national governments and multi-lateral institutions as well as standards, regulations and, practices across different regions shape global debate on STI cooperation for the achievement of SDGs. In this regard, the range and diversity of global efforts to formulate and manage STI policies to achieve SDGs becomes apparent through the assessment of some of principal interests, obstacles, areas of confrontation, and cooperation [7,10,14].

The UN has called for global integration of SDGs into STI to enhance economic growth and prosperity around the world [15]. Addressing part of the challenges in SDGs requires effective implementation of an STI system in low-and middle-income countries. Evidence shows that the wealthiest countries dominating global research and development have strengthened their economies and suited their production and consumption patterns for several decades rather than meeting global social needs [16,17]. This is reflected in massive research and development investments that have shaped global agriculture, pharmaceutical, transport, energy, infrastructure, and other economic sectors. Technology has revolutionized how these industries conduct their businesses and enabled businesses to foster product development, diversification, and market penetration. Indeed, technology ownership dominated by high-income countries has raised many questions about whether low-and-middle-income countries are paying enough attention to technology development underpinned by science and innovation to promote economic growth and solve social problems. The dominance of a few companies in a global market is partly due to their ability to harness science and innovation to develop new technology. This is particularly true as technologies that could benefit social development are frequently held by the private sector in high-income countries. For example, the private sector accounts for more than 66% of global research and development spending, primarily targeted toward narrow goals and business interests in high-income countries [18]. The fact that the private sector controls intellectual property rights makes access to technologies for social benefits a daunting task [19]. Limited access to technology has been argued to be one of the key reasons for inequality between high, low-and-middle income countries [20]. It also presents a significant challenge to the achievement of SDGs. In light of this challenge, technology and the combination of STIs can play an important role in the achievement of the SDGs. However, how STI is prioritized in national innovation systems to achieve the SDGs, especially in low-and-middle-income countries, remains unclear. In this regard, the inclusiveness of technology-enabled solutions is critical to addressing agenda 2030 particularly, global production, consumption, food insecurity, poverty and climate change [15,21].

Evidence suggests limited participation of the global south scientific community in formulating SDGs. This has been attributed to a widening gap of science and research between high and low-and-middle-income countries. For example, in 2014, the OECD countries accounted for more than 3500 researchers per million inhabitants when compared to 70 per million inhabitants in high income countries [18]. African countries remain at the bottom of the table with only 2.6% contribution of total scientific publications in 2014. This shortcoming prevents them from active engagement at the international level due to lack of knowledge-based and context-specific transformation pathways. Moreover, inadequate investment in research and development might have not only contributed to limited engagement in formulation of the SDGs and the ability of low-income countries to realize SDGs. Yet, the UN system continues to call for the increased participation of low-and middle-income countries to ensure successful implementation of SDGs.

An international interdisciplinary team has identified critical elements of national and international policies and strategies to deliver SDG STI solutions. The aim was to create a framework that fosters a systemic approach to planning and undertaking the required actions to facilitate the work of national governments and international development agencies globally. To the best of our knowledge and reach, only a few studies have explored interdisciplinary STI in the context of achieving SDGs and have directly addressed research questions around: 1) the integration of SDGs into STI cooperation; 2) the need for increasing levels of participation by the global South scientific community in the implementation of SDGs; and 3) STI-based solutions relevant to the achievement of the SDGs.

To this end, we assessed the perspectives of relevant stakeholder groups (i.e., policymakers, academia, donor, private sector and non-governmental organizations) through an international survey (see methods) on the role of STI in tackling SDG challenges in three main themes: 1) agriculture (SDG1 and SDG2—no poverty and zero hunger), 2) health (SDG3—ensure healthy lives and promote well-being for everyone of all ages), and 3) environment and energy (SDG7—ensure access to affordable, reliable, sustainable and modern energy, and SDG13—take urgent action to combat climate change and its impacts).

Method

Objectives and Research Design

This study examines the role of Science, Technology and Innovation (STI) and the factors that facilitate and/or hinder the effective implementation of SDGs, especially in Low- and Middle-Income Countries (LMICs). According to the World Bank's fiscal year 2024 classification, LMICs have a Gross National Income (GNI) per capita between $1,136 and $4,465 [22]. These countries are generally in a transitional phase, experiencing some economic development and improvement in living standards.

To achieve the study objectives, a two-stage approach was applied: (1) a survey with stakeholders and (2) the development of a framework.

(1) Survey with stakeholders

Questionnaire development and measurement scales

First, based on meetings, experience-sharing of the authors as *ad hoc* experts in the field, related reports [23,24], and literature review [25–27], a questionnaire was developed to capture the main obstacles, challenges, solutions, and reinforcing or conflicting mechanisms on how STI can be applied to achieve SDGs. The 2030 Agenda highlights the integrated nature and indivisibility of the 17 sustainable development goals; yet acknowledges that different countries set their priorities according to their national context. Hence, SDG1 (no poverty), SDG2 (zero hunger), SDG3 (health and well-being), SDG7 (energy), and SDG13 (climate change) were selected in this study, considering their shared relevance and the positive impacts STI can bring to their implementation in LMIC (UN Note SDGs VNRs) [28]. Furthermore, previous research highlights that connections between the SDGs must be identified and tackled, increasing the need for partnerships and effective collaboration between different stakeholder groups, as SDG17 aims for [2]. Moreover, SDGs were centered on three main themes: 1) agriculture (SDG1 and SDG2- no poverty and zero hunger), 2) health (SDG3—ensure healthy lives and promote well-being for all at all ages), and 3) environment (SDG7—ensure access to affordable, reliable, sustainable and modern energy and SDG13—take urgent action to combat climate change and its impacts). These themes were recently suggested in a book that covers many pressing problems and current opportunities, emphasizing the role of STIs in developing countries. The book was edited by researchers from the team of authors and compiled 26 chapters written by 71 authors from 18 countries (Adenle et al., 2020) [25].

The questionnaire was developed in English and structured in the following sections: i) socio-demographic information of the respondents; ii) obstacles in the application of STI and challenges in the STI cooperation between low-middle and high-income countries; iii) solutions to achieve SDGs 1, 2, 3 (including COVID-19 recovery), 7 and 13; and finally, iv) reinforcing/conflicting interactions between STI interventions and the achievement of SDGs (e.g., cheap energy can increase the access to basic services, but also for additional demand, generating negative environmental impacts).

It is important to determine respondents' perceptions on the obstacles, challenges, and solutions of STI given the relevance to the SDGs. Researchers have used a similar approach to explore the link between obstacles/challenges and solutions to gain insights into the implementation of new policies [26,27]. To assess the responses, 5-point Likert scales (Importance) were applied, ranging from (1 = Unimportant, 2 = Of little importance, 3 = Moderately important, 4 = Important, and 5 = Very important); the mean values of each scale item are presented in the results. The internal consistency of the scales was measured with Cronbach's Alpha [29]. Cronbach's alpha tests to see if the multiple-question Likert scale surveys are reliable. It is a measure of internal consistency, i.e., how closely related a set of items are as a group. It is a function of the number of test items and the inter-correlation among the items. In this study, the scales measuring Obstacles (0.825); Challenges (0.777); Solutions for SDG1 (no poverty) and SDG2 (zero hunger) (0.819); Solutions for SDG3 and COVID-19 recovery (0.804); and Solutions for SDG7 (energy) and 13 (climate change) (0.819) obtained satisfactory reliability values (>0.7) as described by Hair and his group [30,31].

Sampling and data collection

The online survey was conducted between July 2021 and February 2022, and a stakeholder-based survey approach [26] was used. This means that information from a broad range of stakeholder groups (including academic researchers, policymakers, donors, agents of the private sector, and non-governmental organizations) around the world was collected. It is assumed that those multiple actors who are actively involved in the STI and SDG debates are also well-informed and aware of the challenges LMICs face. Moreover, it is possible to go beyond simple questions designed for citizens who do not feel familiar with the issue. Finally, analyzing stakeholders' perceptions can lead to strategic decisions in the public and private spheres to support STI and the successful implementation of SDGs in LMICs.

Survey invitations were distributed to the professional networks of the interdisciplinary study team via e-mail and relevant social media websites (Facebook, Twitter and LinkedIn). These social media networking sites also extended generic invitations, personal invitations, and group invitations. All invitations specifically included the request to share and further distribute the invitation with additional professional networks. The snowball method was used to reach more targeted respondents [32].

Online surveys commonly face selection and respondent bias where the population to which they are distributed cannot be described, and respondents with biases may select themselves into the sample [33]. To mitigate the challenges, surveys were targeted through professional networks. The invitations consisted of a brief outline of the study and who was required and had the profile to complete it. The online questionnaire was anonymous, following the ethical approval guidelines, and did not ask for personally-identifiable information. The research team acknowledges that sampling bias does not allow the statistical generalization of the results. Yet, through convenience and purposive sampling, findings relevant to a sub-population of interest (in our case, experts and stakeholders with knowledge of STI and SDGs) could be identified.

In total, 199 responses were collected from questionnaires distributed around the world. The survey was programmed to require the respondents' consent to participate in the survey and only forms that included answers for all the required questions could be finalized and submitted to the server. It is estimated that the survey reached out to more than 1,000 academic researchers and more than 500 different stakeholder groups including the private sector, NGOs and donors. This represents a response rate of approximately 13% which is considered acceptable for surveys online [34]. To reduce the response bias (i.e., situations where people do not answer questions truthfully for some reason), the study followed best practice recommendations (e.g., the survey was short and to the point to avoid respondent fatigue, the language was unambiguous and the questions were interesting and relevant to the respondents, keeping them engaged). To reduce non-response bias (i.e., when those unwilling or unable to take part in a research study are different from those who do), the team reinforced the contacts with key stakeholders and kept the data collection flexible (via emails and social media, snowball sampling), but focused on the target group [35]. It is important to acknowledge that STIs can facilitate the achievement of SDGs in different countries, but the challenges and obstacles are higher for LMICs. For that reason, the survey was distributed in a systemic way to the target sample, (i.e., irrespective of the country of origin of the stakeholders). Future research might explore the perception of stakeholders located in LMICs or High Income Countries, for example, since results could provide different perspectives and segmented strategies for the achievement of the SDGs.

The final sample was composed of 199 participants (52.8% male and 47.2 female, 81.4% postgraduate, 40.7% ranging from 36–49 years old) belonging to relevant stakeholder groups (e.g., academia (42.2%), international (13.6%) and non-governmental organizations (18.6%), policymakers (15.1%), donors (1%)).

(2) Framework Development

The second methodological approach is based on the assumption that the SDG framework lacks a holistic approach that recognizes the interconnectedness among its goals and targets. Indeed, progress toward one goal could either impede or enhance progress towards other goals, as described by previous studies [61,62]. To address the challenges and complexities of integrating Science, Technology, and Innovation (STI) into SDG achievement, a comprehensive framework is proposed, focusing on four key dimensions: i) national planning; ii) resource and capacity building; iii) engagement and partnerships, and iv) access. These dimensions are substantiated by the literature [63–65] and by the viewpoints of the authors. Data from the stakeholders' survey (as described beforehand) encompassing a broad spectrum of STI-related issues are crucial for attaining the SDGs and advancing towards an overall sustainable development agenda, all of which complements the framework development. The framework will be presented in detail in the next section.

Ethics approval

Ethics approval (2021-IRB16) was granted by the Institutional Review Board of the International Center for Tropical Agriculture (CIAT). For inclusion in the study, respondents were required to complete three levels of voluntary consent: (i) the participant agreeing to participate after reading the purpose and nature of the study, (ii) the participant granting permission for the responses to be used in research publications; and (iii) the participant granting permission for the research to use direct or attributed quotations from the interview.

Results

Factors hindering STI applications in low- and middle-income countries

Two sets of questions were applied to better understand the factors hindering STI applications in low- and middle-income countries.

First, survey respondents were asked to rate the importance of obstacles (Fig 1A) in applying STI in achieving SDGs. As described in Fig 1A, seven obstacles were considered to be very important. Nevertheless, "poor infrastructure" (including "agriculture and food distribution, and health systems") was considered the most important obstacle in applying STI to achieve

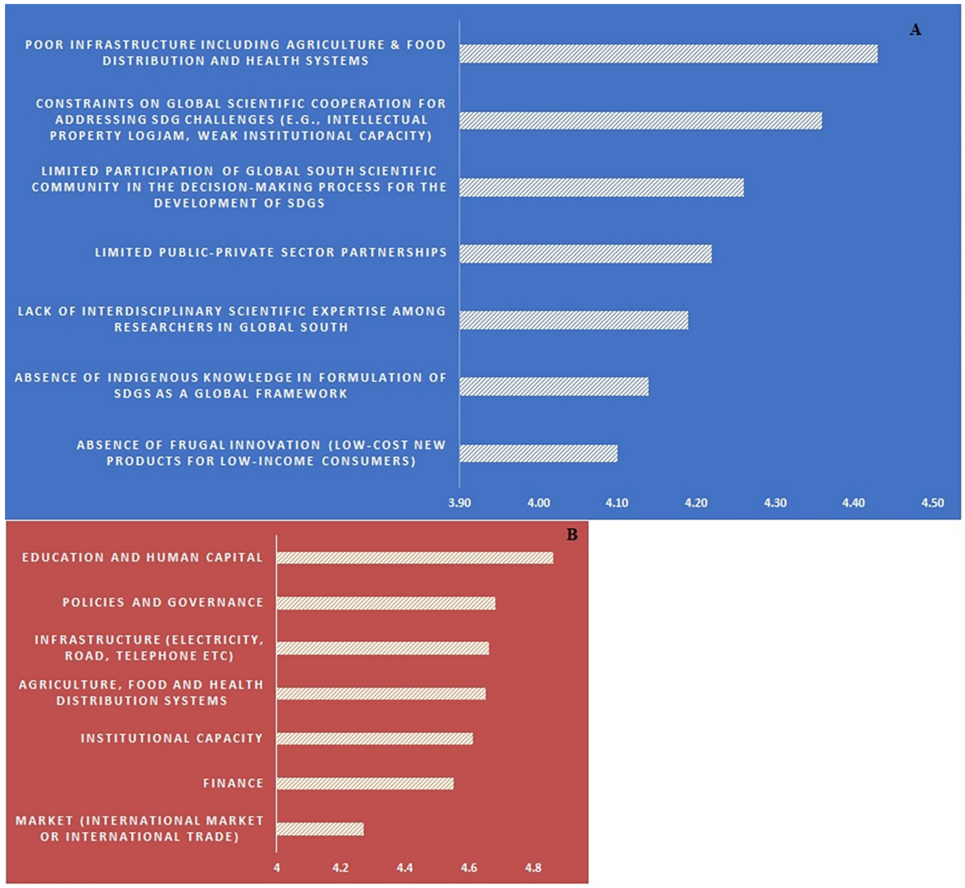

Fig 1. (A) **Current obstacles in applying STI to achieving SDGs in low- and middle-income countries.** Bars represent mean scores, based on a 5-point Importance (Likert) Scale. (B) **Current challenges in achieving cooperation between high income and low- and middle-income countries to provide STI solutions for SDGs.** Bars represent mean scores, based on a 5-point Importance (Likert) Scale.

https://doi.org/10.1371/journal.pstr.0000085.g001

SDGs, followed by "constraints and limitations related to cooperation of the global scientific community".

Next, respondents were asked to indicate the degree of importance of different factors to overcome some of the challenges while stimulating the cooperation between high-income and low- and middle-income countries in providing STI solutions for SDGs (Fig 1A). They indicated that limited participation of the global south scientific community, limited public-private partnerships, lack of interdisciplinary, absence of indigenous knowledge in the formulation of SDGs, and absence of frugal innovation for the basis of the pyramid, as hurdles for the application of STI in LMICs. These instances demonstrate the increasing need to integrate the global scientific community's perspectives into the decision-making process for cooperative STI policy [7].

To overcome these barriers and stimulate cooperation between high-income and low- and middle-income countries in providing STI solutions for SDGs, respondents indicated education and human capital as the most important factors followed by policies and governance, infrastructure and distribution systems (agriculture, food, and health). Our findings are consistent with evidence provided by recent literature on these topics, concerning the significant role played by these factors on global development and SDGs. Concerning education and human capital, Angrist et al (2021) [36], Pubule et. al (2021), [37] and Ryymin (2021) [38] provide evidence supporting our results and the need for an integrated approach to these topics, supported by innovation frameworks, digitalization, knowledge governance strategies and knowledge-sharing systems. Institutional capacity, finance, and international market/trade were ranked as relatively less important, although all factors are considered important (Fig 1B).

Solutions to achieve SDG1 and SDG2

STI solutions such as improved infrastructure, agriculture, and food distribution systems in low- and middle-income countries (representing roads, ICT, post-harvest technologies, etc.) obtained the highest degree of importance for SDG 1 and SDG 2, followed by equitable access to innovation to fight poverty and strong national innovation systems (Fig 2). Prioritization of local innovation also obtained the same importance for SDG1 and SDG2, while free access to intellectual property received a much lower score.

Our findings agree with recent literature data on ICT and post-harvest technologies concerning the major role played by these factors on global development, sustainability and achievement of SDGs, especially with respect to SDG1 and SDG2. Evidence from these studies corroborate our findings and indicate the critical role played by local innovations [39,40] and the presence of good infrastructure for improving sustainability practices in development projects both in agriculture, supporting food distribution systems [41]) and health, supporting distribution and availability of vaccine and drugs [42–44].

Solutions to achieve SDG3 and COVID-19 recovery

The same approach was applied in the health section to assess how STI solutions are relevant to achieving SDG3 targets and COVID-19 recovery. The importance of six solutions is shown in Fig 3 below.

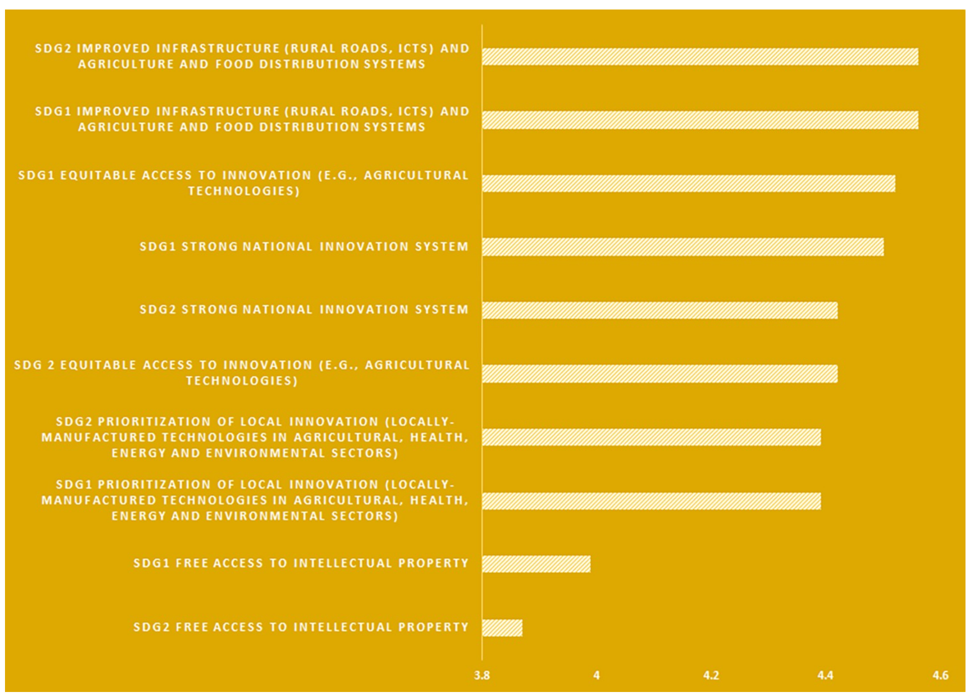

Fig 2. STI-based solutions are relevant to achieve SDG 1 and SDG 2 targets. Bars represent mean scores, based on a 5-point Importance (Likert) Scale.

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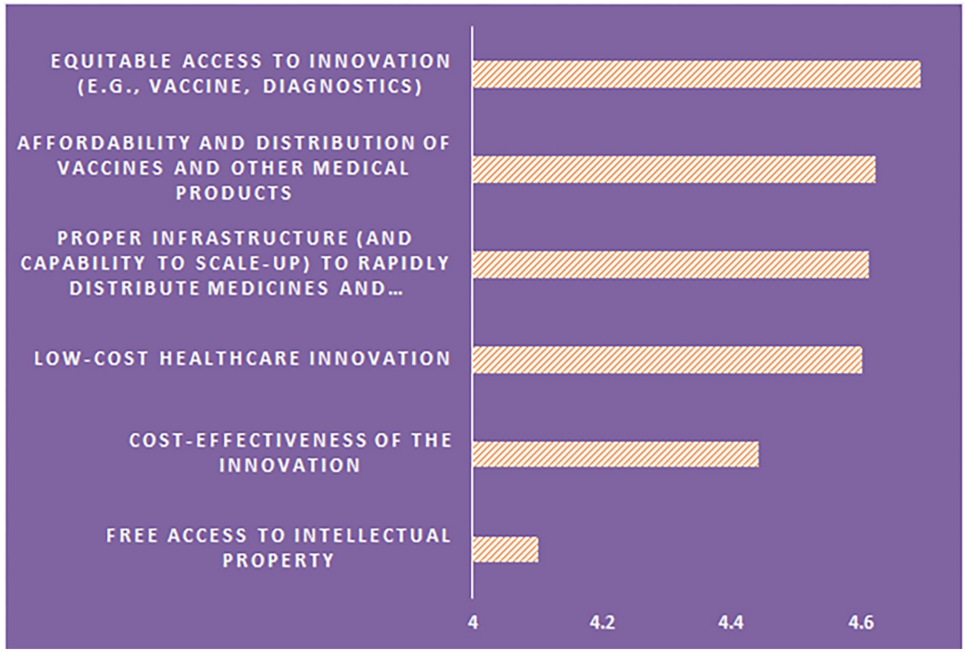

Fig 3. Importance of STI solutions in achieving SDG3 and COVID-19. Bars represent mean scores, based on a 5-point Importance (Likert) Scale.

https://doi.org/10.1371/journal.pstr.0000085.g003

Equitable access to innovation (vaccines, diagnostics) was considered the most important factor in achieving SDG3 and COVID-19 recovery, followed by affordability and distribution of vaccines and other medical products, proper infrastructure for rapid scaling and distributing medicines, vaccines, and food to the population (e.g., cold storage facilities in remote areas) and low-cost healthcare innovation (Fig 3). As reported by Lehoux et al (2015) [45], our findings further underscore the need to address equity and sustainability challenges as related to lack of access to health innovation (including vaccines and diagnostics) and limited infrastructures that are resulting to poor delivery of healthcare services in LMICs. The cost-effectiveness of the innovation and free access to intellectual property were rated lower relative to the other issues, but were still deemed important (above 4). The fact that the two factors were deemed important suggests that the STI approach to health innovation is primarily driven by dominant multinational IPR and speculative investment where short-term profits/returns supersede long-term health gains and well-being of society in poor countries [45,46].

The importance of accessing innovations and complementary solutions in strengthening the distribution infrastructure is critical in achieving SDG3. A reliable supply chain infrastructure in conjunction with information systems would facilitate rapid scale-up of clinical solutions and relevant knowledge of safe and effective use of STIs at the local levels. Furthermore, for affordable STI solutions to be developed, additional effort is required to improve the capacity to generate evidence at multiple levels from evaluating the STI with respect to safety, equity, and local adaption to optimize the potential benefit at the community level. Hence, the improvements and alignments of digital and transport distribution infrastructure are equally important [47]. Investment in improving generic digital and health literacy at the local community level would enhance the readiness for rapid scale-up of STI solutions such as COVID-19 testing and vaccine rollout.

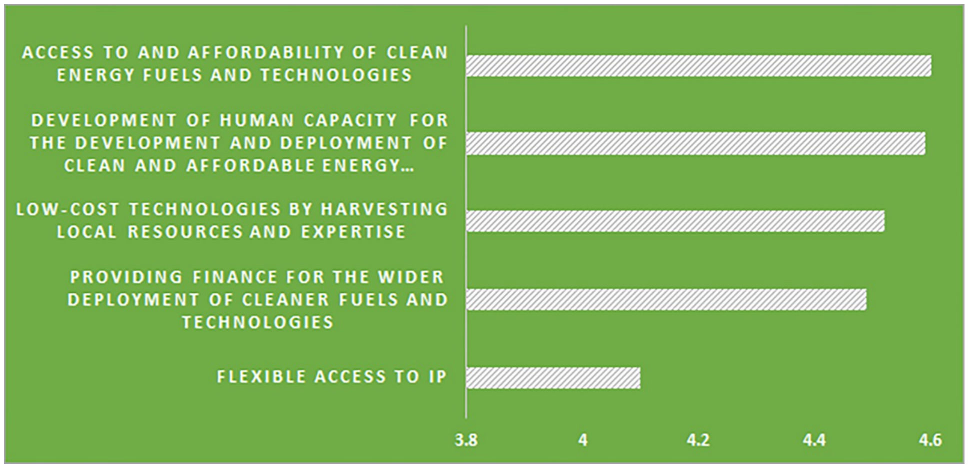

Fig 4. STI solutions relevant to achieving SDG7 (Ensure access to affordable, reliable, sustainable, and modern energy) and SDG13 (Take urgent action to combat climate change and its impacts) targets. Bars represent mean score, based on a 5-point Importance (Likert) Scale.

https://doi.org/10.1371/journal.pstr.0000085.g004

Solutions to achieve SDG7 and SDG13

With respect to the environment and energy sector, respondents evaluated the role of STI in achieving SDG7 and SDG13. Access and affordability of clean technology fuels obtained the highest mean score rating, followed by the development of human capacity for the development and deployment of clean and affordable energy technologies and low-cost technologies (Fig 4). Renewable energy sector is strongly connected with climate change mitigation and adaptation and numerous literature evidence have established their correlation and interdependency, especially in terms of research and development, access and affordability of clean technologies. For example, the IPCC report [48] argues the that lack of R&D represents a significant challenge to deployment of clean technologies in low-and middle-income countries, which is in line with our findings. Financing was also a major factor driving STI in meeting SDG7 and SDG13, though considered slightly less important than the top three in implementing the sustainable development agenda. Yet, weak financing instruments undermine the implementation of low carbon technologies in LMICs [49,50]. Flexible access to IP obtained the lowest mean score, but once again, all factors were considered important (above 4.0).

While LMICs have increased R&D expenditures over the past two decades, these are still relatively low in many countries. For example, Sub-Sahara Africa invests an average of 0.25% of GDP in R&D programs despite recommendations by the Africa Union to invest at least 1% [51,52]. Without substantial financial resources, LMICs cannot implement green economy projects (SDG7) or perhaps meet the Paris Climate Agreement (SDG13). While the importance of STI for achieving the SDGs is well-recognized in high income countries, STI policy applications to support sustainable development goals are limited in many developing countries due to financial and structural impediments [53,54].

Intended and rebound effects

The role of STI in mediating SDG linkages remains mostly unexplored. Behavioral and systemic responses that counteract environmental gains from technological change, so-called rebound effects, could expose hidden barriers toward an internally consistent application of the SDG framework. For example, the linkages between energy, poverty, and climate goals are mediated via energy efficiency improvements [55]. A better understanding of rebound effects could improve our understanding of STI-mediated SDG interlinkages, investigate the SDG framework's consistency as a whole, and assist in identifying appropriate management strategies to mitigate undesired effects.

This is in line with the recommendations of the International Council for Science and the International Social Science Council (2015) to associate goals with specific resource intensity targets [56]. To capture stakeholders' views and guide future research, respondents were also asked to rate the importance of various STI-mediated reinforcing (mutually beneficial) and conflicting (mutually hindering) interactions between individual STI interventions to achieve the SDG framework. Interactions focused on rebound effects, often observed in policies aimed to increase the efficiency of utility services (e.g., energy and water efficiency) and land/agriculture productivity [57].

For each topic, reinforcing interactions were generally rated higher than conflicting ones across demographic groups while also describing the highest variation or lower consensus (Fig 5). Our results describe a stark contrast with the focus of the rebound effect literature, which is dominated by conflicting interactions on energy efficiency and energy in general [58]. Such interactions are perceived among the least important (average score of 3.5 for energy efficiency) while also describing the highest asymmetry between conflicting and reinforcing mechanisms. The detrimental effects of energy inefficiency on energy use and related carbon emissions is also widely acknowledged as critical to sustainable development and environmental policy effectiveness [57,59]. Our results may suggest that, rather than being insignificant, this particular topic may be factored in. In other words, the current body of evidence is extensive and research on this topic already yields low marginal returns in this context. In addition, the mainstream research focuses on the detrimental effects from energy efficiency, which may be perceived as insufficient to unravel the complex interactions that impede the achievement of the SDG framework. Demographic variables cannot be disregarded as mainstream research is largely carried out by males from academic institutions in high-income countries. In line with recent calls for a greater alignment with sustainability science [60], and

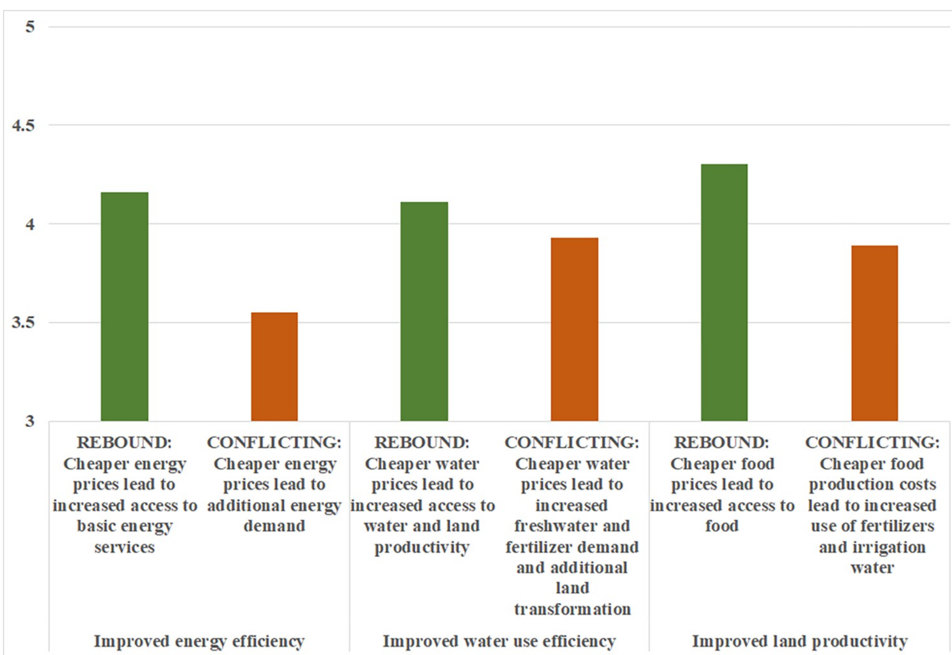

Fig 5. Experts' mean scores on reinforcing and conflicting (rebound) effects.

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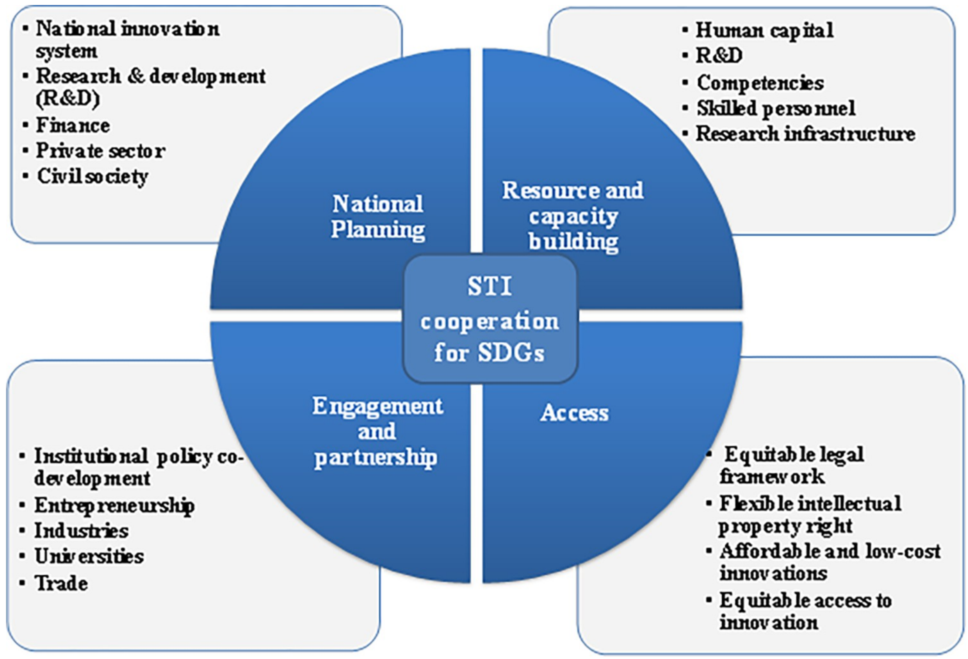

Fig 6. A framework illustrating STI cooperation for the achievement of SDGs. Source: authors.

https://doi.org/10.1371/journal.pstr.0000085.g006

with the help of stakeholders' views, greater efforts must be redirected towards reinforcing interactions to unveil welfare-enhancing effects as well as overlooked topics such as agricultural land productivity and increased water use efficiency. Clear goals and metrics should be established, and activities planned for each STI initiative to improve clarity and accountability.

From the outset, the SDG framework lacked a systems approach that addresses the inherent linkages across goals and targets. In fact, progress towards one goal could either hinder or reinforce progress towards other goals [61,62] as supported by stakeholders' viewpoints.

Below, we present a framework for STI cooperation for the SDGs focusing on four dimensions: national planning, resource and capacity building, engagement and partnerships, and access to innovation to deal with the challenges and issues in achieving the SDGs (Fig 6). These dimensions are elaborated in Table 1 and also touch on significant aspects of each dimension that can foster STI cooperation. Further, these dimensions reflect the authors' viewpoints supported by survey data, which are described across a wide range of STI issues for achieving SDGs. The dimensions highlight the need to gain insights into potential multi-sectoral inter-linkages across SDGs to enhance cooperation among various actors at the national or global level. These insights would be a prerequisite for understanding broader consequences relating to the application of STI and collective action in evaluating them. With this approach, an integrated natural and social sciences will be useful to policymakers, the research community, the business community and the broader society in innovation thinking, interactive design, transition management, awareness creation and responsible scaling as well as multidisciplinary sustainability science for the achievement of the sustainable development agenda such as SDGs [63–65].

Discussion and conclusion

Our findings reveal some fundamental challenges that could undermine the effective implementation of SDGs in LMICs. Challenges such as the lack of proper engagement of the global south scientific community and lack of interdisciplinary are hurdles that should be addressed

Table 1. STI cooperation for SDGs: cross-sectoral perspectives.

Engagement and Partnerships	National Planning	Resourcing and Capacity Building	Access
Public-private partnerships	Multi-actor governance. Clear goals and metrics	Incentives for innovation and Innovative funding mechanisms	Support to "frugal innovation": affordable, equitable, and cost-effective solutions
Multi-level cooperation	Role of STI in mediating SDG linkages	Role of international and national donors	Incentives to flexible patent systems and accelerate technological transfer to developing nations
STI-based policies-Partnerships for Product Development	Research on "rebound effects¨: behavioral and systemic responses	Build responsive capacity to novel developments, not just capacity to utilize existing technologies.	Provide "patent pools" and other innovation incentives to increase access of the resource-poor to new agricultural technologies, vaccines, and drugs. Overcome technical, legal, and institutional barriers to knowledge transfer.
Research-community partnerships in the developing world	Evaluation and monitoring. Long-term strategic plans	Increase complementary investment for educational and research infrastructure	Follow-up access and quality indicators with innovative digital technologies
Civil society engagement	Advocacy-organizing services and activities (research and innovation). Improving impacts on government policy	Participation of stakeholders in resourcing and capacity building. Enabling policy co-design	Participation of local organizations in access and quality monitoring

Source: elaborated by the authors.

https://doi.org/10.1371/journal.pstr.0000085.t001

to foster STI collaboration between the global South and North. Identifying and prioritizing SDG interactions require scientific collaboration through an interdisciplinary approach [66]. The global community should encourage scientific research partnership opportunities for the global South to unlock transformational capacity of science, research and training while sharing its gains equitably. It is important to encourage interdisciplinary research partnership that allows contributions from natural sciences, social sciences, life science and engineering among others. SDGs will not be achieved without emphasizing the importance of interdisciplinarity and scientific engagement within STI systems at the national and international levels [18,66].

Indigenous knowledge and frugal innovation could be recognized as critical components of STI towards the achievement of SDGs in low-and-middle income countries. Moreover, the fact that indigenous knowledge and frugal innovation do not reflect the broader objectives of the SDGs have drawn criticism from various key stakeholders [56,67–69]. This essentially means that the way in which either local knowledge or frugal innovation is perceived has not received much-needed attention from the key actors especially the UN body, international donors and the private sector. The failure to recognize that development needs must take into consideration Indigenous peoples' experiences in LMICs may undermine the achievement of SDGs at the local level. Our study is in agreement with Cummings (2017) who argued that "the SDGs are fundamentally flawed because they are not based on local realities and local knowledge"[70] p22). Furthermore, the lack of specific mentions of frugal innovation in the formulation of SDGs suggests that its contributions to sustainable development in rural areas may be overlooked. Yet, frugal innovation offers a promising approach for sustainable development through frugal enterprises and economic growth as well as social-influence impacting aspects such as poverty and health concerns. A growing body of literature has documented the critical role of frugal solutions in terms of sustainable enterprise, business model, supply chain management and environmental sustainability at the grass root level in low-and-middle income regions [71,72]. The authors argued that frugal innovation such as low-cost technologies can deliver affordable solutions to consumers in important sectors including agriculture, education and health. In light of this potential, it is therefore important to harness the transformational role of local knowledge and local innovations to achieve the SDGs.

The role of ICT and agricultural technologies as relevant STI solutions cannot be overemphasized in improving agricultural productivity and the food system, while tackling poverty in low-and-middle income countries. Currently, inappropriate land use and food systems are contributing to persistent hunger, malnutrition, and obesity [73], with poverty being a leading cause of persistent hunger. At the same time, agriculture and food systems underpinned by STI present a means to reduce poverty and ensure sustainable, safe, equitable and healthy diets for all [25]. Several studies indicate that new technologies and innovations are required to transition to sustainable agriculture and food systems to achieve economic growth, and human and planetary health [25,74–76]. The importance of STI solutions in strengthening the agricultural and food system is vital for escaping poverty (SDG1) in agriculture-based economies such as sub-Saharan Africa and South Asia. As noted in the era of green agricultural technology revolution, STI approaches such as improved infrastructure and national research and development programs tailored towards high-yielding varieties helped efforts in hunger and poverty reduction in Asia [77]. A strong R&D system supported by STI competencies calls for planning development projects that mainstream SDG2 into national innovation policies in low- and middle-income countries. Therefore, integrating STI policy into national development planning in relevant sectors is critical to achieving the SDGs.

The STI cooperation between high-income and low- and middle-income countries underscores the role of STI in achieving the SDGs in agriculture, health, environment, and energy systems using key indicators to solicit viewpoints from different stakeholder groups. The survey respondents considered education and human capital (4.86 out of 5) as the most significant factor for STI cooperation, followed by policies and governance (4.68) and infrastructure (4.66). Respondents' viewpoints suggest that interventions in science and innovation skills and industrial policies are limited in most low- and middle-income regions. The fact that education and human capital were best rated for STI cooperation among respondents means that national and international governments need to pay adequate attention on investments in human capital development, research and acquisition of basic skills, to foster effective implementation of SDGs. Specifically, national governments should promote the creation of opportunities for industries by supporting scientific R&D for innovation-driven economies, and build their abilities through education and training policies. The research gap between high-income and low- and middle-income countries reflects the underlying challenges for international STI cooperation. The fact that STI human resource capacity is still very weak in many developing countries, even in the middle-income ones, suggests that achievement of SDGs 1, 2, 3, 7 and 13 will require strengthening the educational system, increasing investment in R&D programs and providing adequate infrastructure and expertise for the requisite skills and competencies to foster STI cooperation. According to Fonseca et al. (2020), SDG1 (poverty elimination), and SDG3 (good health and well-being) have synergetic relationships with most of the SDGs, while SDG7 (affordable and clean energy) has a significant relationship with other SDGs (e.g., SDG1, SDG2 (zero hunger), SDG3, SDG8 (decent work and economic growth), and SDG13 (climate action)). Hence, effective measures for advancing the SDGs and, ultimately, sustainable development for all demands that the relationships and interactions between the SDGs must be identified and tackled. In this sense, the discussion on conflicting and reinforcing effects following the rebound effect framework and the body of work sheds relevant insights for further research and ultimately towards an effective implementation of the SDG framework. Furthermore the SDGs' synergies and trade-offs represent an opportunity for policy and decision-makers by suggesting that the frequently linear development paths of economic growth ahead of social equity and environmental protection might be challenged by other systematic approaches that offer multiple solutions and drivers for different contexts.

In this regard, the four key components of the framework (Fig 6) will require many low- and middle-income countries, if not most, to undertake a shift in public policy at the national level for STI cooperation. Achieving SDGs in many low- and middle-income countries will depend on both domestic innovation and catching up technologically to position their national innovation system and policy environment to take the best advantage of knowledge transfer at the global level for STI cooperation.

For STI cooperation to happen, the transformation of industry, universities and research institutes in low- and middle-income countries is crucial to complement mutual strengths and a win-win approach in key areas, such as institutional policy and governance structure, higher level of scientific training, entrepreneurship, research infrastructure, legal framework and technology transfer.

STI solutions for SDGs should be created, including co-funding of R&D by international donors and national governments and effective protection of intellectual property rights, but not to the point where it restricts access to frontier technologies and discourages private sector innovation. A committed and systematic approach can overcome technical, legal, and institutional barriers related to financing STI solutions in low- and middle-income countries.

Capacity-building programs for STI need to be implemented at the sub-national, national, and regional levels, aiming for whole-of-country capacity-building rather than narrow, single-industry approaches. Further, the aim should be to build the necessary capabilities for novel developments, not just the capacity to utilize existing technologies. Complementary investments in educational and research infrastructure are crucial.

Our survey findings and allied research indicate that Science, Technology, and Innovation can be powerful tools to reduce social exclusion and extreme poverty in the world, and are much needed, for example, in the current COVID-19 pandemic. STI can also contribute to improved quality of and access to public services. Although scientists have historically made significant contributions to innovation and technological development of processes and products, only a small part of these contributions have effectively been incorporated into global social welfare. This scenario urgently needs to be changed. New STI governance structures, policy strategies and incentives for Southern scientists are required to successfully integrate STI policy into social policies.

Limitation and future research

The study is beyond the scope of assessments of the impacts of STI for achieving SDGs in low- and-middle income countries as the study only focuses on the viewpoints of selected stakeholder groups around the world. The viewpoints of these stakeholders are not representative of all, which is one of the limitations of this study. In addition, almost 200 respondents were analyzed across thematic topics so it is not possible to generalize the results. Given the importance of this study and its contribution to the literature on STI/SDG, it is worth assessing the impacts of STI towards achieving SDGs at the national and regional levels. In this regard, this study can help gain insight into the role of each component in tackling the challenges in SDGs and interactions across different goals, while considering the synergies and trade-offs in the process leading to the achievement of SDGs.

Acknowledgments

Special thanks to Africa Sustainability Innovation Academy in leading and coordinating the research. Authors would like to express their appreciation to Cyrus Muriithi (Alliance of Bioversity International and CIAT) for the support in programming and administering the online survey. We thank Prof. Adelaide Antunes and Dr. Alessandra Moreira de Oliveira (Federal

University of Rio de Janeiro and the Brazilian National Institute of Industrial Property) and Dr. Akira Homma (Bio-Manguinhos, Oswaldo Cruz Foundation) for their valuable support in coordinating the application of the questionnaires in Brazil. Authors are grateful to the editor and two reviewers in providing constructive comments that have improved the quality of the final manuscript.

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