

# Co-development of technologies of the future



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## Introduction

Globally, technology and innovation are both extensively recognized as powerful tools to address and combat climate change. Technology transfer and associated financing have been critical demands, particularly from developing countries, for more than two decades of climate negotiations (Ghosh, 2015). This was a critical element in the 26th Conference of the Parties (COP26) held in Glasgow in November 2021, with developing countries including India calling for a deal for development that is just, equitable, people-centric and planet positive (Ghosh, 2021).

Technology transfer is paramount for development, particularly for low- and middle-income countries (LMICs) to accelerate their expertise, experience and equipment related to advanced, innovative industrial products and processes (International Federation of Pharmaceutical Manufacturers & Associations, 2011). Effective technology transfer could help countries secure national supply and reduce their dependence on imports, and advance several Sustainable Development Goals (SDGs), including SDG 3 (Good health and well-being), SDG 7 (sustainable energy for all), SDG 8 (Decent work and economic development), SDG 9 (Innovation, industry and infrastructure), SDG 13 (Climate change) and SDG 17 (Global partnerships). Moreover, technological transformation plays a critical role in meeting global ambitions for climate change, curbing emissions via access to mitigation technologies and building the necessary resilience for countries, cities and communities via access sharing of adaptation knowledge and methods (Ghosh et al., 2019).

Transfer of advanced technology is a challenge for developing countries and emerging markets. It is critical that new or existing technologies are locally adapted, inculcating the challenges and the opportunities for the country. For instance, in countries with a lack of cold-chain storage, how can vaccines be stored in sub-zero temperatures and transported in warm and tropical climates? Given this, it is important that technology development conducted for the global stage must involve multidisciplinary teams and research and development (R&D) that recognize such challenges (International Federation of Pharmaceutical Manufacturers & Associations, 2011).

## BACKGROUND PAPER

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Despite decades of discourse on technology transfer and collaborations, there is still limited understanding of the factors responsible for successful technology transfer and partnerships. Hence, to explore how technologies of the future should be co-developed, it is imperative that we first understand how current technology transfer and collaborations in critical sectors have fared so far. This paper analyses three key research questions on technology transfer, collaboration and co-development to reimagine a new global technology order.

1. Has technology transfer delivered on sustainable development?
2. What are the different types of emerging climate-friendly technologies and associated uncertainties?
3. What are the modalities for successful technology co-development?

## History of technology transfer and the Stockholm Convention

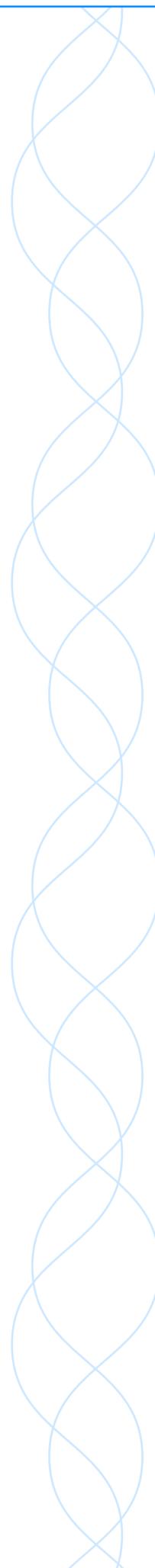
The inception of technology transfer from developed to developing countries dates back to 1963 to the first United Nations Conference on Science and Technology for the Benefit of the Less Developed Areas. This idea was later entrenched into several other UN programmes, but stalled on account of unresolved political debates on costs, management, suitability and ownership. 'Technology transfer' was then mentioned in some capacity in the 1972 United Nations Conference on the Human Environment (Stockholm Conference) (Gillespie, 2006). The Stockholm Declaration and Action Plan for the Human Environment provided the first globally agreed set of 26 principles that placed the environment at the 'forefront of international concerns' and ignited the dialogue between developed and developing countries on interconnecting issues of economic growth, air and water pollution, and well-being of people around the world.

### Technology transfer in the Stockholm Convention

These founding principles have underpinned environmental discourse for over half a century (Gillespie, 2006). In the context of this paper, two principles focus on (science and) technology and its transfer to developing countries.

Principle 18 of the declaration states: 'Science and technology, as part of their contribution to economic and social development, must be applied to the identification, avoidance and control of environmental risks and the solution of environmental problems for the common good of mankind' (United Nations Environment Programme, 1972, p. 5). Several countries suggested proposals during the drafting of this principle. However, none of the proposals, neither by industrialized or developing nations, highlighted the need for technology collaboration.

That said, there was one suggestion on the lack of international cooperation 'in the application of modern science and its transfer to developing countries' (Sohn, 1973). This suggestion was included as part of Principle 20: 'Scientific research and development in the context of environmental problems, both national and multinational, must be promoted in all countries, especially the developing countries. In this connection, the free flow of up-to-date scientific information and transfer of experience must be supported and assisted, to facilitate the solution of environmental problems; environmental technologies should be made available to developing countries on terms which would encourage their wide dissemination without constituting an economic burden on the developing countries' (United Nations Environment Programme, 1972, p. 5).



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Despite suggestions from countries to strengthen this principle, the final iteration missed the mark. For instance, the needs of developing countries were no longer given priority, although provisions have been made to make environmental technologies available to them. Moreover, instead of the principle concluding on a more affirmative stance on free of flow of scientific information, it settled on a more nuanced position that environmental technologies 'should be made available' (Sohn, 1973, p. 485).

Technology transfer, as a desired outcome, continues to remain without certainty or specifics within the larger international arena. How can Stockholm+50 encourage and change the current landscape of technology development and lay down new standards to promote a deal for development that is just, equitable, people-centric and planet positive?

#### The way ahead to Stockholm+50 and beyond

The upcoming Stockholm conference in June 2022 marks 50 years since the 1972 Stockholm Conference that made the critical linkage between environment and poverty. Now, 50 years later, the world faces a triple planetary threat of climate change, pollution and waste, and nature and biodiversity loss that affect current and future prosperity and well-being.

Despite 50 years of talks of technology transfer, the development and production, affordability, allocation and deployment of technology across all sectors still remains skewed towards the developed world. Given this, Stockholm+50 can recognize the importance of multilateralism and bring together nations and stakeholders to collaborate on technology, share expertise and address the nexus for urgent actions and long-term systematic change. Unlike climate and trade negotiations, just as in 1972, Stockholm+50 provides a non-negotiated platform to bring together countries to chart a new future for technology co-development. This will act as a springboard to accelerate the implementation of the UN Decade of Action on the Sustainable Development Goals, Paris Agreement, and Immunization Agenda 2030, and support the adoption of post-Covid green recovery plans.

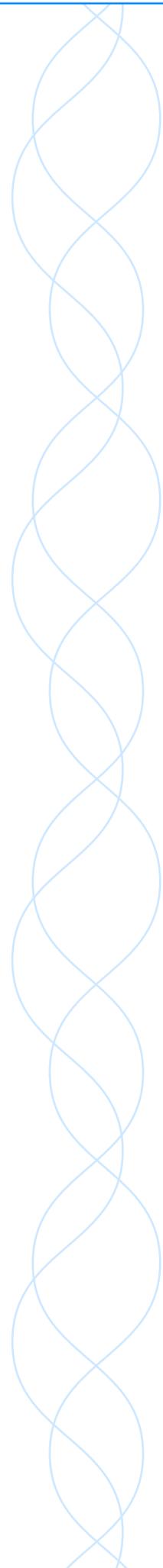
#### Changing the narrative from technology 'transfer' to 'co-development'

*Give a man a fish and you feed him for a day.  
Give a man a fishing rod, and he feeds himself and his family for as long  
as the rod lasts.  
Help a man develop the knowledge and means to improve the fishing rod  
and to design and produce new ones, and he may feed himself and his  
society for years to come.*

(Cannady, 2006).

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Technology transfer is not as simple a process as putting these two words together. It goes beyond supply, demand and shipment of hardware across international borders (Organisation for Economic Co-operation and Development & International Energy Agency, 2001). Technology transfer in the dynamic sense is the sharing of ideas, knowledge and adaptive technologies to meet local conditions and strengthen human and technological capacity in these areas, with particular focus on developing countries (Organisation for Economic Co-operation and Development & International





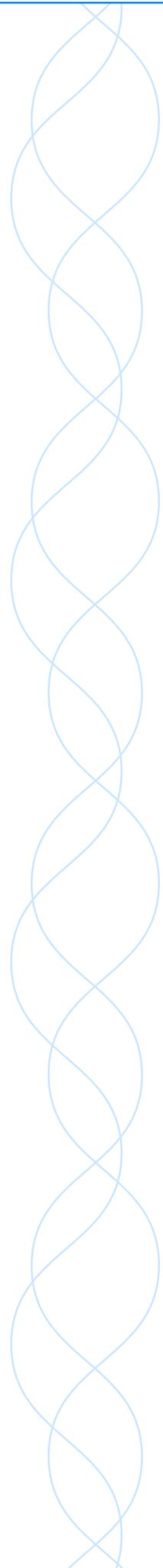
Energy Agency, 2001). This transfer globally aims at boosting commercial markets, especially for frontier technologies critical for achieving the SDGs. Although technology transfer is a critical element of global negotiations, particularly in the climate domain, globally there is still limited understanding of what works and what does not (Ghosh, 2015).

Enabling developing countries and least developed countries to bypass fossil fuels and directly shift to climate-friendly and sustainable solutions is possibly one of the biggest technology challenges worldwide. This requires developed countries to deploy clean technology and 'democratize' environmentally friendly know-how (Matthews, 2021). The latter is true also for other sectors of the economy such as agriculture and health, as seen during the Covid-19 pandemic.

According to the *Global Energy Alliance for People and Planet* launched at COP26, energy-poor countries currently account for 24% of global emissions (Matthews, 2021). If these countries continue to rely on fossil fuels for economic growth, their contribution will increase to 75% by 2050, surpassing the global carbon budget of the planet (The Rockefeller Foundation, 2022). For greenhouse gas emissions to hit net zero by mid-century, developing countries cannot follow the same path of 'dirty' development and growth as developed countries and must leapfrog to build a cleaner and greener economy. For countries like India, where steel manufacturing is a critical economic sector both for micro, small and medium enterprises (MSMEs) and the country's overall GDP, there is a critical need, particularly for MSMEs, to adopt cleaner technologies for production at the same pace as the developed world, rather than wait for green technologies to mature in the West.

For this to occur, frontier technologies need to be disseminated at similar paces globally. However, so far this has not been the case. For instance, according to Malpani and Maitland (2021), only 14% of the promised vaccines have been delivered by the developed countries as of October 2021, while Western pharmaceutical companies only delivered 12% of the doses allocated to COVAX, the initiative designed to assist LMICs to attain fair access to Covid vaccines. This lack of equitable technology transfer is also true in the energy sector. Currently, 759 million people globally still lack access to basic electricity. According to the International Energy Agency (IEA) et al. (2021) current policies estimate that 660 million people in sub-Saharan Africa will still lack access in 2030, while developed countries transition from coal to natural gas to renewable energy and green hydrogen for sources of energy. For technology to be disseminated more equitably, both developed and developing countries need to close the ever-widening gap on capacity, climate finance, and technology transfer and capability, and developed countries need to fulfil their commitments in aiding the developing world. Moreover, if technologies of the future (for continued progress towards sustainable development) widen the technology gap or if these technologies become less accessible and affordable for the majority of the world's population, then such a scenario would be inconsistent with the 2030 Agenda for Sustainable Development of just and inclusive sustainable development for all.

This paper suggests that the global community needs to push out the phrasing of 'technology transfer' from negotiations and implementation frameworks as a means to achieve sustainable development. To reimagine a new global technology order, a shift is needed in how technology development is approached. All technologies consistent with sustainable development and those that require scaling must be co-developed, with active involvement from the Global South. This would promote transparency and ensure equity in access, use and monitoring between advanced and developing economies, as well as inculcate practices and expertise from the Global South that are pertinent to the adoption and implementation of frontier technologies in these regions.



### Current challenges with technology transfer

In 2001, the United Nations Framework Convention on Climate Change (UNFCCC) embedded the technology needs assessments (TNAs) to support national sustainable development and capacity building and facilitate the implementation of prioritized (climate) technologies. Since 2001, more than 90 developing countries have conducted TNAs to address climate change, which has led to the identification of key barriers that restrict transfer, access and use for mitigation and adaptation technologies. Technology cooperation across all geographies and sectors, including those beyond climate, are restricted by financial, technical and policy barriers that are corroborated by gaps in information, human skill and institutional capacity.

The barriers are many. First, costs of technology vary by geography. In sub-Saharan Africa, the cost of lithium-ion batteries is nearly 2–4 times higher than in other parts of the world (Matthews, 2021). Second, the cost of finance to deploy technology is also higher in developing countries. In many of the least developed countries, the cost of financing for renewable energy projects is 6–7 times higher than in rich developed countries (Matthews, 2021). Intellectual property rights (IPRs) are another barrier, which can delay rapid technology dissemination. During the Covid pandemic, many rich nations and the EU refused to support the proposal to waive patents on vaccine technology and many leading pharmaceutical companies were unwilling to share their technology with the World Health Organization (WHO), thus delaying the start of low-cost manufacturing in the developing countries (International Energy Agency et al., 2021; United Nations Conference on Trade and Development, 2021). Furthermore, innovation and localized adaptation of novel and existing technologies are critical for efficient use and distribution and to prevent delays in technology introduction. But in many LMICs, lack of adaptation of vaccines to endemic strains and lack of storage facilities for transportation in tropical climates have resulted in lags in adoption.

### Current status of technology collaboration

The paper analyses the current status of technology collaboration and whether technology transfer has been success in three key sectors: clean energy and climate, agriculture, and vaccines and tropical diseases. The paper applies the Technology Mechanism (Article 10) of the Paris Agreement as a general guiding framework to review 30 multilateral agricultural initiatives and 36 multilateral clean energy initiatives in the last decade (2010–21). The technology framework presents five focus areas that have been used for evaluation: Innovation; Implementation; Enabling environment and capacity-building; Collaboration and stakeholder engagement; and Support (United Nations Framework Convention on Climate Change, 2015). Since the Paris Agreement explicitly focuses on climate change, this framework was not suitable for evaluating global international initiatives on technology transfer for vaccines and tropical diseases. Therefore, the paper reviews literature to evaluate the state of technology transfer in this sector.

The following sections will delve more deeply into the nature, scale and geography of technology transfer, indigenous knowledge inclusion and whether technology transfer goes beyond soft transfer such as knowledge sharing and preliminary R&D activities to focus on hard transfer such as equipment, joint production and co-development.





## Clean energy

The paper reviews 36 multilateral clean energy initiatives in the last decade (2010–21). Within the clean energy space, 27 out of 36 initiatives provide global coverage while 5 focused primarily on developed countries and 4 on developing countries. Out of the list of 36, only 2 initiatives – Powering Past Coal Alliance and R20 – focus at a subnational level. This is a critical point of reference as global initiatives need to become more localized at the national and subnational levels for greater inclusivity and accountability of a country’s economic, political and social indicators to scale up global initiatives (Ponzio & Ghosh, 2016). Assessing Low-Carbon Transition was the only international initiative to create an accountability framework and sectoral methodologies to assess how company strategies and actions contribute to the Paris Agreement mitigation goals. Lastly, the Coalition for Sustainable Energy Access, launched in 2021, was the only initiative to explicitly state strengthening South–South cooperation in technology transfer and improving the understanding of roles of existing institutions and initiatives in the Global South.

The largest number of initiatives – 27 out of 36 – focus on forming an *enabling environment and capacity building for technology transfer*. Nearly one-third of the initiatives focus on facilitating information-sharing and networking among relevant institutions to enable exchange of best practices on technology development. There is limited focus by any of these initiatives on actual technology transfer beyond soft transfer of skills and practices. Other activities under this focus area include enhancing public awareness; facilitating countries to enable an investment-friendly environment; assisting countries in developing and implementing policies to incentivize the private and public sectors; enhancing collaboration with existing capacity-building organizations; and enhancing the capacities of Parties to plan, monitor and verify technological transformations. Finally, there was nominal focus on promotion of endogenous and gender-responsive technologies and capacity enhancement of national designated entities,<sup>1</sup> particularly in developing countries.

*Support for technology transfer* was the next most populous focus area with 14 initiatives. Here too priority was heavily skewed. Whereas six initiatives focus on identifying or promoting financing, whether finance was delivered, how much and to whom needs to be evaluated. There are four initiatives – Carbon War Room, European Technology and Innovation Platform for Wind, Mission Innovation, and Under 2 Coalition – that focus on developing or improving systems for monitoring and tracking actions to contribute towards the transparency framework under Article 14 of the Paris Agreement.

*Collaboration and stakeholder engagement and innovation for technology transfer* have six and eight initiatives, respectively. Under innovation, none of the eight initiatives focused on promoting or supporting countries in joint international climate technology research, design and development (RD&D) partnerships or increasing the participation of developing countries in collaborative approaches to RD&D.

*Implementation of technology transfer* accounts for the smallest number of initiatives, with only 4 out 36 initiatives, and the priority areas are still highly skewed. Over 75% of the initiatives focus on identifying and developing recommendations to enhance the enabling environments and address the barriers for development and transfer of climate-technologies. None of the initiatives focused on facilitating TNAs and capacity building related to TNAs or identifying and developing recommendations on approaches for technologies that are ready to transfer.

<sup>1</sup> National designated entities act as focal points for interacting with the Climate Technology Centre and Network and serve as national entities for the development and transfer of technologies (Climate Technology Centre & Network, 2015).



### Agriculture

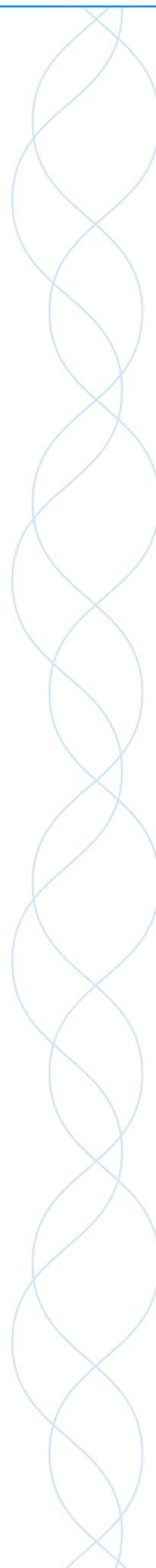
The paper reviews 30 multilateral agricultural initiatives in the last decade (2010–21). Within the agricultural domain, 22 out of 30 initiatives provide global coverage, while 3 initiatives focus primarily on developed countries and 5 on developing countries. Only one initiative, Nature4Climate, aims at establishing a coordinated effort to address the totality of natural climate solutions. The Tropical Forest Alliance 2020 is the only initiative to specifically focus on increasing participation of developing country Parties in collaborative approaches to RD&D. Despite the localized connotation of agricultural initiatives, the Research Program on Climate Change, Agriculture and Food Security is the only initiative to explicitly focus on downscaling of climate issues into agriculture policies at the subnational level.

The largest number of initiatives – 21 out of 30 – focus on forming an *enabling environment and capacity building for technology transfer*. A majority of the initiatives focus on facilitating information-sharing to enable the exchange of best practices on technology development and transfer and enhancing the capacities of Parties to plan, monitor and verify technological transformations. A few initiatives also focus on formulating and analysing information on capacity-building activities at different stages of the technology cycle (unlike the clean energy initiatives) and enabling countries to enhance an investment-friendly environment for technologies. Ironically, while several initiatives focus on ‘bring[ing] back indigenous rights to the local people’, not one initiative focused on harnessing indigenous knowledge for technology transfer. Moreover, these initiatives also lacked efforts to build an enabling environment to promote indigenous and gender-responsive technologies, even though women make up over 25% of the global agricultural labour force (World Bank, 2021). Efforts were also lacking in assisting countries in developing and implementing policies to incentivize the private and public sectors, and in enhancing collaboration with existing capacity-building organizations to create synergies and enhance efficiency, which is particularly critical for this interlinked sector.

The second most populous theme is *innovation for technology transfer*, with 15 multilateral initiatives addressing this theme. Knowledge sharing on international technology RD&D partnerships, promotion, development, deployment and dissemination of existing innovative technologies and scaling up emerging climate technologies are prioritized the most. Moreover, only one initiative – the Tropical Forest Alliance 2020, launched in 2012 – specifically focuses on ways to increase effective participation of developing country Parties in collaborative approaches to RD&D.

*Support for technology transfer* has eight initiatives, with three focusing on promoting innovative finance and investment at different stages of the technology cycle, while the rest are scattered between providing enhanced technical support to developing country Parties and enhancing the collaboration of the Technology Mechanism with the Financial Mechanism.<sup>2</sup> Only one initiative focuses on developing a system for monitoring and tracking of activities undertaken by the Technology Mechanism to enhance transparency. The focus areas on *collaboration and stakeholder engagement* and *implementation of technology transfer* have three and two initiatives, respectively, in the last decade.

<sup>2</sup> The Financial Mechanism under the UNFCCC serves as the financial mechanism of Paris Agreement, under Article 9. The aim of this mechanism is to ensure efficient access to financial resources through enhanced readiness support and approval processes for developing country Parties, particularly least developed countries and small island developing States for their national climate strategies (UNFCCC, 2015).





Across the entire list of 66 initiatives only a few are designed to extend beyond knowledge exchange and include some preliminary RD&D activities, with even fewer focusing on real technology and equipment transfer, collaborative production and joint dissemination mandates. Not much has changed over the past decade as these findings concur with an earlier analysis of technology collaboration platforms, prior to the Paris Agreement (Ghosh, 2015). One of the major drawbacks identified throughout this analysis of the technology framework of the Paris Agreement is that there is limited explicit focus on developing countries. Out of 35 action areas under the five focus areas, only three action areas specifically mention developing countries. Moreover, while a few action areas mention ‘technology transfer’ there is no mention of technology co-development or collaboration between the Global North and South or South–South cooperation.

### Vaccines and tropical diseases

Newly emerging and re-emerging infectious diseases have threatened humanity throughout history. Currently, the world is witnessing a once-in-a-century global health pandemic, which has resulted in more than 5.5 million deaths worldwide as of 11 January 2022 (Worldometers, 2022), upended supply routes that took decades to build and destabilized the global economy. The Covid-19 pandemic serves as a watershed moment for global health emergency preparedness, critical investment into 21st century public services and resilience of supply chains. It also underlines the stark contrast of two worlds – the haves and have-nots – and that no one is safe, until all are safe.

The achievement of SDG 3 (Good health and well-being) is closely linked with the progress of reducing the burden of infectious diseases, with efficient immunization, in some cases, to be the most effective health intervention. While vaccines generally take 5–10 years to develop, with some taking nearly four decades in the case of Ebola, the Covid vaccine was developed by numerous countries in record time with nine currently approved by the WHO (Zimmer et al., 2022).

Development and production of vaccines is only one-third of the challenge. The next phase is (equitable) access to vaccines at affordable prices. Global vaccine roll-out in LMICs has always lagged behind high-income countries. In 2010, a decade after the introduction of the pneumococcal conjugate vaccine, only 2% of LMICs had it in their immunization schedule as opposed to 87% in high-income countries (Gavi, the Vaccine Alliance, 2007). Similarly, by 2001, 20 years since the licensing of the hepatitis B vaccine, only 28% of people in Southeast Asia were covered by the vaccine, despite the fact that hepatitis B is endemic there, compared to 90% in America (Gavi, the Vaccine Alliance, 2007).

The story is no different another two decades later in 2022. As of 11 January 2022, over 4.67 billion people have received a dose of the Covid-19 vaccine, equating to nearly 60.8% of the global population (Holder, 2022). However, the spatial dispersion of vaccines across the world is not uniform. Africa has seen the slowest immunization rate, with only 13.9% of the entire continent’s population receiving at least one dose of the vaccine. Over 72% of vaccines have been administered in high and upper-middle income countries, with LMICs taking a meagre share of 0.9% (Holder, 2022). This is despite the efforts of COVAX, which aimed to provide 2 billion doses by 2021. Export bans, production problems and vaccine hoarding by rich countries have been the main reasons why COVAX has missed its target (Zimmer et al., 2022). These lags, unfortunately, are the norm rather than the exception for adoption of new vaccines in LMICs. The inequities of this situation are all the more indefensible since a vast majority of mortality from vaccine-preventable diseases occurs in LMICs (Cragger, 2018).



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There have been several global initiatives to bridge this gap. However, many have been unsuccessful in meeting their stated objectives. In 2010, the global health community declared the period 2010–20 the Decade of Vaccines, with the vision for all individuals and communities to live free from vaccine-preventable diseases. In 2012, the Global Vaccine Action Plan was endorsed, with one of the objectives as ‘all immunization programs to have sustainable access to universally recommended vaccine technologies within 5 years of licensure’. These were both ambitious targets and neither was met. In reality, the global coverage of essential vaccines has stagnated. However, progress should not be viewed in binary terms of ‘met/not met’ as this does not highlight the changes made in the last decade (Strategic Advisory Group of Experts on Immunization, 2019). Measles immunization has prevented 21.1 million deaths and reduced the reported incidence by 83% since 2000 (Strategic Advisory Group of Experts on Immunization, 2019). The past decade also saw the fastest introduction of new vaccines in LMICs; however, the overall roll-out of vaccinations has been unequal, both within and between countries.

In order to ease access to and dissemination of vaccines in developing countries and LMICs, it is critical to overcome the high costs of vaccines and technology, and IPR challenges. It is also vital to reduce market entry timelines for developing country vaccine manufacturers and streamline regulatory pathways for biosimilar vaccines through technology transfer and know-how (Strategic Advisory Group of Experts on Immunization, 2019). However, this is easier said than done, as most LMICs still lack the technical know-how and manufacturing infrastructure for vaccine production. In Africa there are fewer than 10 domestic vaccine manufacturers, with limited upstream production capacity as most local companies only engage with the labelling and packaging (World Health Organization, 2021). Moreover, medical technologies and vaccines usually come at a very high cost, resulting in out-of-pocket payments as the primary source for covering costs. Finally, there is a stark contrast between research and demand. Less than 25% of all biomedical research publications and 33% of clinical trials in Africa relate to diseases involving 50% of the infections in the continent (So & Ruiz-Esparza, 2012).

The only way to accelerate technology transfer and global vaccine production in developing countries and LMICs is by promoting joint ventures between global vaccine manufacturers and local pharmaceutical companies to create regional manufacturing hubs. Such hubs would be financially supported by the host-country government, Global North and international organizations to bridge the issue of limited investment (Fu et al., 2021). These joint ventures would also target problems with patented and tacit knowledge of production and shortage of inputs for production, and provide access to a large local or regional market. Furthermore, for such joint ventures to succeed in technology collaboration it is also necessary for the host country and government to create an enabling local environment for innovation and research infrastructure and establish policies such that existing generic manufacturers are not squeezed out of the market.

Some scholars also suggest that focusing on the pharmaceutical value chain offers insights in technology innovation and access. Successful interventions across the value chain of artemisinin-based combination therapy (ACT) shaped its availability and affordability to treat malaria. For instance, the Affordable Medicines Facility-malaria negotiated with manufacturers to lower the cost of ACT, exercised innovative financing and co-payments to subsidize the purchase of ACTs, and promoted interventions to encourage rational use of the treatment (So & Ruiz-Esparza, 2012).





Finally, South–South technology cooperation is also critical in this sector. In 2008, Farmanguinhos, Cipla and Drugs for Neglected Diseases Initiative (DNDi) increased the decaying shelf life of Artesunate-mefloquine (ASMQ) via technology transfer in warm tropical countries (Drugs for Neglected Diseases initiative, 2009). Such initiatives provide a positive signal for foreign direct investment and create potential for developing countries to work together to build a healthier economy.

## Technologies we need for the future

The above section laid out what has happened so far on technology transfer and the need for technology co-development to bridge the gap between the two worlds of haves and have-nots. However, Stockholm+50 could be about reimagining future technologies and their joint development to gain global benefits. As we outline a reformed paradigm for technology collaboration, it is imperative to understand the different categories of future technologies that will anchor the human response to climate change, and pave the way for sustainable development in the coming decades. Table 1 presents the categorization based on the corresponding degrees of risk and declining appetite for private investment for these technologies (Ghosh, 2020).

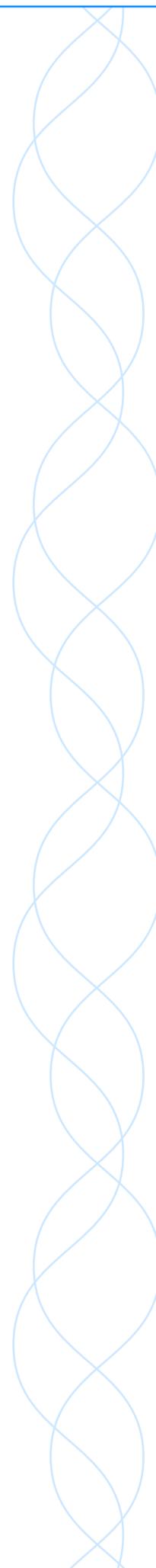
Table 1: Categories of innovation and technologies of the future

Technology type	Basis	Example
Transitional technologies	Technically proven but need local adaptation	Bioenergy; agricultural tools and techniques for climate-resilient and high yield crops; electric mobility; storage
Innovations for resilience	To combat climate risks	Nature-based solutions and climate-resilient infrastructure
Foundational technologies	Applicable across many sectors, but need policy direction and public–private co-financing	Green hydrogen; circular economy of critical minerals; nanotechnology; biotechnology
Breakthrough technologies	Significant disruptive potential but with major risks	Climate geoengineering: carbon capture, utilization and storage; carbon dioxide removal; solar radiation management; space technology

Source: Ghosh (2020).

## Uncertainties associated with future technologies

Processes for technological development and scientific innovation run in parallel with uncertainty. For every potential technology, there lie inherent uncertainties pertaining to development pathways, economic growth, technology costs, socio-political factors, and secondary and tertiary impacts. Each technology will have a specific set of uncertain impacts, which has implications for technology cooperation (Ghosh et al., 2019).



Co-development of technology allows for pooling of resources among countries and sharing of the co-benefits. Co-development is a feasible route for reducing costs for development, especially with resource-intensive technologies such as nuclear energy, green hydrogen and vaccine development. Drop in costs significantly impact penetration in markets. Uncertainty about the long-term impact of new technologies, or about the ways to deal with those impacts, can affect their investment, development and deployment.

Dimensions of uncertainties evolve and interact with each other. Understanding the dynamic and complex relation of uncertainties is vital for reducing them and enabling more effective decision-making. Reducing uncertainty is key for both framing intent and informing governmental policy, market signal and stakeholder investment in new technology, as well as avoiding lock-ins. Thus, technology collaboration and co-development are closely linked to how related uncertainties are understood and reduced.

### Modalities for technology collaboration

It is important to assess methods for effective technology co-development in the face of the urgent global crises of climate change and public health (such as dissemination of vaccines, as observed during the Covid-19 pandemic). It is, therefore, necessary for countries and institutions to understand the needs of participating countries and examine existing institutional national arrangements for technology co-development and draw in lessons from international mechanisms.

### Ease of licensing and co-owning of intellectual property rights

A major hurdle for diffusing advanced technologies to developing countries is the existing IPR regime. Governments in developed countries play an important role in funding R&D programmes, but the technologies developed are seldom in the public domain or available without cost. In most cases, patent rights are distributed to recipient research institutions which subject publicly funded patents to royalties, licence fees and so on (Sathaye et al., 2005). Clean energy patents are largely privately owned and concentrated in developed countries. Thus, the speed of diffusion of advanced energy technologies is largely determined by companies and institutions in the OECD countries (Lee et al., 2009). In 2005, India's country paper to the G8+5 Summit explicitly called for placing some IPRs in the public domain, primarily in the areas of energy efficiency and clean energy.

For climate-friendly technologies that require cumulative or incremental innovation, 'open source' registration of the intellectual property (IP) could be promoted, as was done for the Linux software. This would enable interested parties to tailor technologies to local conditions and improve performance: for example, increasing efficiency of solar cells (Ghosh & Ray, 2015). Another approach is to develop partnerships wherein contributing firms/research institutions would retain their original IP but any new technology would have shared IP, while making it accessible to smaller nations that may not have the capacity to contribute (Ghosh, 2014). The India-US Joint Clean Energy Research and Development Centres on solar energy, energy efficiency and biofuels follow this approach (Ghosh & Ray, 2015). Another approach was taken by India and South Africa at the World Trade Organization meeting in 2020. The two countries proposed the suspension of IPRs related to the 'prevention, containment and treatment' of Covid-19 to allow generic and biosimilar manufacturers to immediately produce more affordable versions of the vaccines, medicines and diagnostics without waiting years for key patents to expire (Fu et al., 2021, p. 2).





Another effective partnership that balances R&D with IPR inclusivity is CGIAR, which works at the forefront of creating international public goods in the field of agriculture, with a focus on easily accessible and globally available data (Ghosh et al., 2015). In 2013, CGIAR adopted its Intellectual Assets Policy to make information products openly available (CGIAR, 2013). Thus, while an underlying research centre can place restrictions on the purposes of developing and improving a product, the final output of the research is made available for use and public research (CGIAR, 2011). CGIAR uses a number of innovative methods to lower IP barriers, such as humanitarian use licences, exclusive marketing rights or time-limited ownership or marketing rights (CGIAR, 2012).

## Pooling of resources through innovative financial and non-financial incentives

Technology collaborations have a greater likelihood of success if participating countries are able to pool resources, in cash or in kind. Pooling resources is better done in a calibrated manner, with each stage of the technological development, testing and commercialization securing new tranches of funding or in-kind contributions (Ghosh et al., 2019).

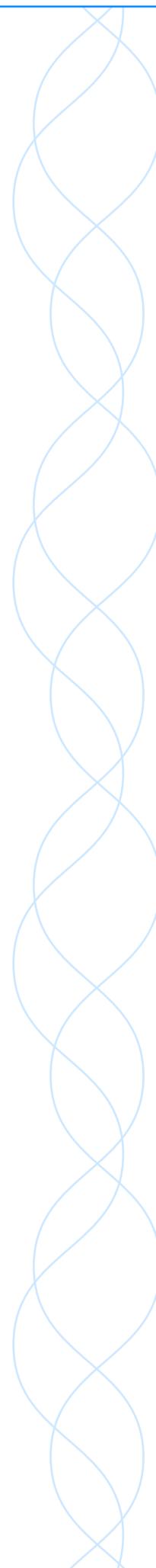
The role of innovative finance and de-risking investment is central to achieving meaningful technology collaboration. Renewable energy and energy efficiency technologies involve higher upfront capital investment as compared to fossil fuel investments (Ghosh et al., 2019). Their infrastructure requires a high volume of de-risked institutional capital, and long-term capital to invest in energy research and development. The energy transition in several emerging economies would be incomplete without international cooperation on innovative finance, hedging multiple financial risks and deepening bond markets.

To meet net-zero commitments and corresponding short-term climate targets, it is essential that high-volume financial investment is channelled to emerging country markets which have higher demand for clean energy, potential for return on investment and growth prospects for renewable industry. In order to achieve this, technology cooperation arrangements will need to address systemic challenges that hinder developing countries from transforming energy systems and applying renewable sources to power industries. This warrants the role of blended and innovative financing to reduce the cost of technologies in developing and emerging markets; opening pathways for increased private sector investment; and reducing the risk perception in developing countries which adversely affects investor confidence.

## Managing risk and liability

Technologies of the future are an exciting proposition but equally risky given the uncertainties involved in their development pathways, impacts and management modalities. Breakthrough technologies, such as climate geoengineering (carbon capture, utilization and storage [CCUS]; solar radiation management [SRM]; and carbon dioxide removal [CDR]) and space technology, have significant known and unknown risks to the planetary environment which can even confine their viability for development. Foundational technologies, such as green hydrogen and circular economy of minerals, require the right development routes in terms of policy and finance, which are critical for overcoming development costs and reducing the risk of losing time in achieving efficacy. Transitional technologies, for example bioenergy and electric mobility, pose lower risks but include the challenge of local adaptation and getting the socio-economic blessing of consumers.

In such cases, technology partnerships serve two purposes: They could draw in a broader set of actors to independently conduct regular risk assessments as the technologies evolve;



and they could serve as a countervailing bulwark against any risky, unilateral behaviour by rogue scientists or technologists (Ghosh et al., 2019). Such safeguarding against substantive and process risks also supports building of trust in these technologies and the institutions that further them. Protocols and frameworks developed by the International Atomic Energy Agency (2011) for risk management of nuclear technology is a relevant reference.

With risk assessments also come the assignment of responsibility and clear rules for liability. Technological innovation within single countries can be governed by domestic laws. But multi-country partnerships need clarification on who bears what kind of responsibility in case of negative impacts and unexpected outcomes. Nuclear energy collaborations have liability provisions, for instance. Similarly, if a coalition of countries decided to implement a large CCUS facility and there was some leakage, the liability of the actual deployment (not just the tech development) has to be clearly established in advance (Ghosh et al., 2019). Such an approach will also allow for transparent and open public engagement from the beginning and promote inclusive decision-making.

How risks associated with technologies of the future are evaluated and addressed in development frameworks is critical. Understanding risks, developing regular assessment frameworks and establishing clear rules for responsibility and liability are key for successful technology collaboration. Existing institutions and new international institutions (to be anchored for governance of future technologies) must embed risk-based approaches in their decision-making and response architecture.

### **Developing multi-stakeholder networks for governance and transparency**

Three obstacles impede technology partnerships: lack of appropriate financing, internet provider (IP) restrictions, and insufficient or underutilized capacity (Jain et al., 2021). For existing technologies, unless adequate financing is procured, deployment at scale is difficult. Entrepreneurs need upfront financing to cover capital costs of clean energy technologies, working capital to hold inventories, and funds to pay IP licence fees. Business models, such as rural micro-grids, could be viable but, being small in scale, they often fail to attract the attention of large institutional investors (Ghosh, 2015).

For future technologies to have global reach and impact, as well as ensure effective dissemination at pace and scale, there is a need to bring together stakeholders from all parts of the governance chain to build inclusive collective networks. Such networks would outline the objectives of collaboration and the approaches to achieve cooperation, and develop frameworks to address risks and ascertain responsibility.

To be effective, partnerships should promote transparency in technology research, development, deployment and commercialization. Networks must contribute to building capacity in weaker partner countries to ensure that deployment is widespread, not captured by a few, as has occurred in the past. Members need not only have to contribute in hard currency. In-kind contributions of research staff, facilities or land for demonstration projects could be ways in which the contributions of all members are recognized and duly rewarded (Ghosh, 2015). This is essential for building trust between parties and developing momentum for incremental action. For example, innovative business models for electric vehicle (EV) financing, decentralized renewable energy (DRE) scaling for livelihoods, or logistics collaboration for fuel testing and experimentation could be enhanced within a multi-stakeholder model involving both public and private players.

In order to achieve inclusivity in technology development, the rules governing voting rights, decision-making procedures, transparency and prior information for affected communities must be determined in advance and revised as the technology evolves or more countries get





involved in the field pilots and commercial testing. This is particularly important for disruptive technologies such as green hydrogen, SRM, and land and ocean-based carbon dioxide removal that presently lack an appropriate governance architecture at the international level. A multi-stakeholder driven, transparent network approach will support in creating early-stage risk assessment frameworks for new technologies and in developing standards for responsible activity and attribution of liability among different actors (Ghosh et al., 2019).

## Redefining technology collaboration

Technology collaboration will play a defining role globally to facilitate equitable access to medical technologies and enable (developing) economies to rapidly transition to a clean energy future to limit average temperature rise to 1.5°C. Countries must not only achieve an all-encompassing energy transition from fossil fuels to renewable sources, but they must do it together, in a manner that is inclusive in scope, equitable in access, people-centric in purpose and planet positive in outcome.

There is a need to move beyond ‘technology transfer’ to ‘technology co-development’ in international negotiations and implementation frameworks as means to achieve sustainable development. This signals a new global technology order, which responds adequately to the climate crisis and lays focus on co-development and co-ownership as the new mantra for technology progression and development globally and throughout critical sectors and industries. All technologies consistent with sustainable development and which require scaling must be co-developed by countries. This would promote transparency and ensure equity in access, use and monitoring between advanced and developing economies.

This paper considers proposals for two future and foundational/breakthrough technologies that could be considered for co-development: green hydrogen and SRM. Both these complex technologies present diverse risks, uncertainties and potential benefits. It is pertinent to note that, on account of their global interest, required transnational governance design and multi-layered impacts, the development journey of green hydrogen and SRM would be most sustainable and safe through co-development that includes the participation of several countries, concerned parties and relevant stakeholders from all parts of the value chain.

## Green hydrogen: roadmap for a global partnership

Without industrial decarbonization, promises of net-zero emissions have little certainty. Industrial emissions must be reduced without deindustrializing fast-growing emerging economies. Green hydrogen, also termed the ‘fuel of the future’, can be a game changer for heavy industries, such as steel, ammonia and petrochemicals, in addition to long-distance freight transport and energy storage. Three trends – expected shifts in sectoral uses, geographical spread to emerging economies, and the need for low-carbon production – will serve as the foundations of a new wave of hydrogen production and consumption in the coming decades.

A Global Green Hydrogen Partnership/ Network (G2H2) should be developed as a multi-country, multi-institutional network to assess, develop and design affordable green hydrogen technologies that can be deployed at scale, in both advanced and developing countries. Similarly, for industries to decarbonize, such a global platform could help bring down the cost of green hydrogen globally and increase its uptake among member countries. G2H2 is essential for the planet to achieve its low carbon development goals in time.



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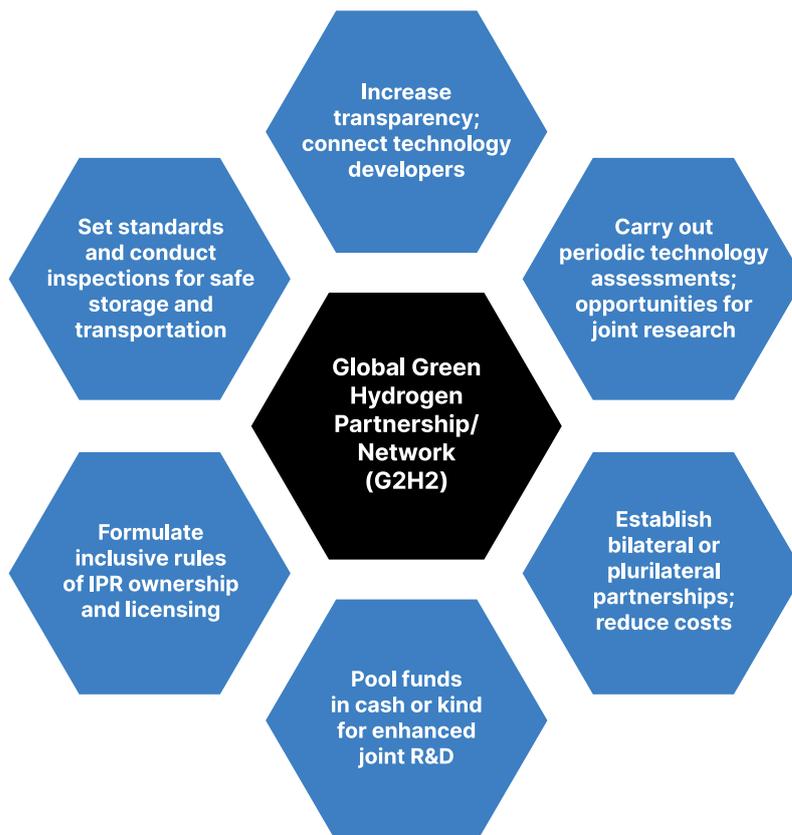
Moreover, it also has the basis and the potential to align public and private interests for efficient and risk-ready scaling of new technology (Ghosh & Chhabra, 2021).

The existing landscape on green hydrogen programmes serves as an ideal opportunity to put forward a new paradigm of technology cooperation. Globally, at least 32 countries, mostly developed, and the EU have announced or are developing national-level policies and strategies for hydrogen. There are more than a dozen bilateral partnerships and at least 10 multi-country or multi-firm platforms focused on hydrogen. But these seldom involve developing countries and are not oriented towards joint technology development. There is a gap between the geographical distribution of green hydrogen potential and the primary destination of investment and projects (Ghosh & Chhabra, 2021). There is a need to pilot green hydrogen projects in countries that will have the greatest demand for cleaner fuels for industrial development.

The G2H2 could create a timely governance and policy apparatus to safeguard energy and decarbonization activities from geo-political tensions, supply chain shortages and high-risk financing. It would involve the segments shown in Figure 1.

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Figure 1: A six step approach to building a Global Green Hydrogen Partnership/Network (G2H2)



Source: Ghosh and Chhabra (2021).

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G2H2 must follow a risk-risk approach, and consider failures in technological development or in end-use applications, second-order risks associated with the adverse impacts of faulty storage or transportation of green hydrogen, and tertiary risks involving trade or intellectual property disputes. G2H2 can also correct for government failures and be tactically and operationally more efficient.



## Governance of solar geoengineering research and technology

Climate geoengineering interventions are often conceptualized as a way to break the link between increasing carbon emissions and rising temperatures. These include different methodologies: first, by removing carbon from the atmosphere (carbon dioxide removal); and second, by reducing the amount of solar insolation reaching the Earth's surface (SRM).

SRM has been at the centre of discussions as a possible but risky option for future action by policy institutions. There are a number of uncertainties surrounding the technical feasibility, economic viability and political motivation behind various SRM technologies. For instance, injecting sulfate particles into the stratosphere could reflect sunlight back into space but could also affect regional rainfall patterns and crop production. The second- and third-order effects of SRM (such as the termination effect whereby stopping an SRM experiment could result in a rapid increase in surface temperatures) add to the technological (and political) uncertainties (Ghosh, 2018).

Irrespective of its use as a deserving technology response to climate change, there is a need to embed the subject matter in the modalities of a renewed technology collaboration order, with a focus on governance of research and decision-making. This is made urgent by the fact that solar geoengineering technologies have the potential to permanently alter climate cycles and disrupt delicate planetary balances. Given this, technology collaboration work on SRM, in particular, and other geoengineering technologies, in general, must prioritize the development of international, multi-stakeholder networks and platforms that aim to: facilitate responsible research; engage openly with the global public; guide all authorized outdoor experiments; balance commercial interests; develop decision-making metrics and rules; and resolve international disputes (Reynolds, Ghosh, Harihar, & Jain, 2022). These would indicate the early and essential steps that countries and international institutions can take to develop an open, equitable and responsible regime to govern a much coveted and equally feared technology of the future.

## Conclusion

Technology transfer and associated financing are critical demands and levers for developing countries to transition to a cleaner, greener and healthier planet. Despite decades of discourse on technology transfer and collaborations, and endorsement and launch of hundreds of different initiatives across sectors, the story in 2022 remains the same. There is now a need to move beyond 'technology transfer' to 'technology co-development' in international negotiations and implementation frameworks as means to achieve sustainable development. This essentially requires an ecosystem where developing countries are not just the recipients but partners in the process of technology development, and to enable technology dissemination at similar paces globally.

Technologies of the future provide a unique opportunity to the global community. For these technologies to succeed in providing accelerated and equitable benefits, it is crucial that stakeholders from across sectors and geographies reimagine and reinvent a new technology order. This is even more necessary to address and minimize the uncertainties, risks and impacts that such pathbreaking technologies will render, and how different countries and stakeholders will be placed in terms of their need, vulnerability and capacity to act on the challenge as well as the opportunity.

All technologies consistent with sustainable development and which require scaling must be co-developed, with active participation from the Global South. The new global technology order must adequately respond to the planetary crises and lay emphasis on co-development and co-ownership as the new mantra for technology progression and



development globally. To accelerate effective usage and scaling up of future technologies, domestic and international actors together must institutionalize the modalities for technology collaboration. This will develop the regulatory apparatus and create the ecosystem to harness opportunities and remove chronic barriers, address user-side challenges, and create facilities that encourage co-development and co-ownership. This approach will yield greater benefits to all stakeholders in the long term.

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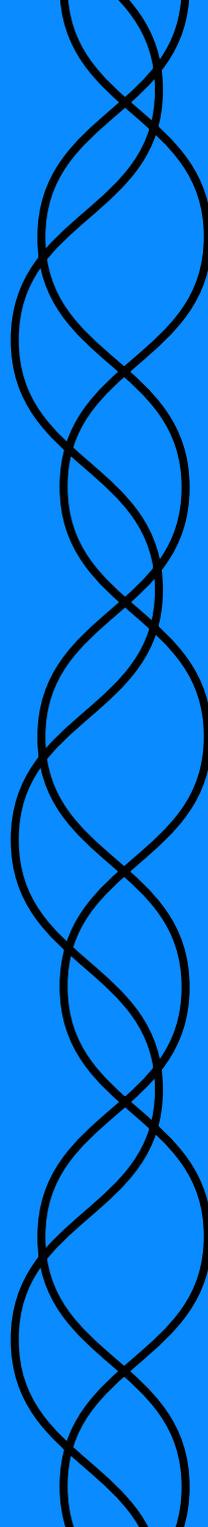


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