CLEANTECH INNOVATION BY DEVELOPING COUNTRIES

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ABSTRACT

Cleantech, technology capable of mitigating or adapting to climate change, is critical for a country to address climate change and build sustainable development effectively. Since the 1970s, the global community has emphasized the voluntary transfer of cleantech from developed countries to developing countries, since the former owns the majority of the existing cleantech and the latter needs cleantech. This focus has produced limited results. This article proposes we shift our focus to global cleantech development and deployment (including international cleantech transfer) instead.

This article proposes a pathway for developing countries, especially the least developed countries, to attract foreign cleantech and develop domestic cleantech. The pathway includes three phases: international aid, international cleantech cooperation, and domestic cleantech innovation. This article suggests that the global community support developing countries in the establishment of their own cleantech innovation systems. Such purposeful support may come in the forms of international aid and mutually beneficial international cleantech cooperation. International aid helps countries, e.g., the least developed countries, to build domestic capacities for cleantech innovation and cleantech importation. Mutually beneficial international cleantech cooperation enables developing countries that have acquired such capacities to move further along toward domestic cleantech innovation. For domestic cleantech innovation, this article suggests that, in principle, a developing country should send clear policy signals to its private sector to indicate the government's long-term commitment to cleantech innovation. This article further proposes that the developing countries leverage diverse innovation tools, including customized intellectual property right (IPR) regimes and non-IPR tools such as prizes and innovation commons.

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CONTENTS

INTRODUCTION

"We must use technology to accelerate climate action and open the door to a stable, secure future on a peaceful, prosperous planet."[1]

Innovation is the main driver for economic growth. Clean technology innovation is critical for the global community to address climate change and build sustainable development effectively. The Paris Agreement declares: "Accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and promoting economic growth and sustainable development."[2] The Technology Executive Committee of the United Nations Framework Convention on Climate Change (UNFCCC)[3] further observed that "to achieve the goals of the Paris Agreement, there is a pressing need to accelerate and strengthen technological innovation so that it can deliver environmentally and socially sound, cost-effective and better-performing climate technologies on a larger and more widespread scale."[4]

For example, cleantech innovation is critical for mitigating climate change. The International Energy Agency — the global authority on climate change science and responses — claims that cleantech innovation must rise by a factor of between two and ten to meet global climate change goals, including reducing

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[1] Nick Nuttall, *Our Climate Crossroads: How Technology Can Lead Climate Action and Sustainable Development*, INT'L INST. FOR SUSTAINABLE DEV. (Oct. 19, 2019), http://sdg.iisd.org/commentary/guest-articles/our-climate-crossroads-how-technology-can-lead-climate-action-and-sustainable-development/ [https://perma.cc/LST6-4K9P].

[2] Paris Agreement art. 10.5, Apr. 22, 2016, T.I.A.S. 16-1104. The Paris Agreement is an agreement under the United Nations Framework Convention on Climate Change (UNFCCC). Drafted in December 2015 and signed by 195 countries, it became effective in November 2016. It is the largest global agreement on climate change up to date, focusing on climate change mitigation and adaptation as well as the associated financing [hereinafter Paris Agreement].

[3] The UNFCCC is the main international treaty designed for addressing climate change. The goal of the UNFCCC is to stabilize "greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." U.N. Framework Convention on Climate Change, June 12, 1992, S. Treaty Doc. No. 102-38 art. 2, 1771 U.N.T.S. 107. The UNFCCC has become the main framework under which global negotiations on addressing climate change occur [hereinafter UNFCCC]. *See* Background on the UNFCCC: The International Response to Climate Change, U.N. FRAMEWORK CONVENTION ON CLIMATE CHANGE, https://unfccc.int/resource/bigpicture/ [https://perma.cc/9QNN-34SY].

[4] *Joint Annual Report of the Tech. Exec. Comm. & the Climate Techn. Ctr. and Network for 2017*, at 11, U.N. DOC. FCCC/SB/2017/3 (Sept. 29, 2017). [hereinafter 2017 Joint Annual Report] The Technology Executive Committee is the policy arm for cleantech development and deployment under the UNFCCC; it focuses on identifying policies that can accelerate the development and transfer of low-emission and climate resilient technologies. *See Technology Executive Committee*, UNFCCC (last visited Apr. 6, 2019), https://unfccc.int/ttclear/tec [https://perma.cc/GP4W-7TT4].

greenhouse gas (GHG) emissions by 50% by the year 2050.[5] The secretariat of the UNFCCC estimates that an additional $200 billion global investment in cleantech research and development (R&D) will be required annually by the year 2030 just to return GHG emissions to 2011 levels.[6] In reality, cleantech R&D global spending is less than about half of that amount.[7] To reduce GHG emissions, an effective pathway is to make low-carbon energy a cheaper alternative than fossil fuels.[8] Only when the price of energy produced from non-fossil fuels is at about an equal or lower price than with fossil fuels, can the global community respond to climate change effectively; only then, would we have a realistic and effective path for mitigating climate change.[9]

Economically, cleantech innovation would drastically reduce the cost of mitigating climate change. Studies have found that accelerated technology development offers the potential to dramatically reduce the costs of stabilizing CO2 concentration in the atmosphere. Expected cleantech advancements may reduce the cumulative costs of stabilization at least 50%, yielding economic benefits of hundreds of billions to trillions of dollars globally.[10] For example, one study finds that expected developments in energy efficiency, hydrogen energy technologies, advanced bioenergy, and wind and solar technologies would save over $20 trillion in CO2 stabilization than if we were limited to technologies available as of the year 2005.[11]

Cleantech innovation is imperative not only for addressing climate change and its impacts ("climate actions") but also for building sustainable development. In 2015, the United Nations (UN) adopted Agenda 2030[12] for global sustainable development, a development that not only addresses our present needs but also leaves room for future generations' needs.[13] Agenda 2030 is a voluntary agreement calling for the global community fulfill seventeen sustainable development goals (SDGs) by the year 2030.[14] Climate actions are

[5] INTERNATIONAL ENERGY AGENCY, ENERGY TECHNOLOGY PERSPECTIVES 44 (2008).

[6] UNFCCC, Investment and Financial Flows: To Address Climate Change (Oct. 2007), https://unfccc.int/resource/docs/publications/financial_flows.pdf [https://perma.cc/GJ8R-EB92].

[7] GENERAL ELECTRIC, INNOVATION, PROTECTION, AND TRANSFER OF GREEN TECHNOLOGIES 3 (2011), https://www.wipo.int/edocs/mdocs/mdocs/en/wipo_inn_ge_11/wipo_inn_ge_11_ref_t.pdf [https://perma.cc/DX5D-XTA6].

[8] MEETING OF THE OECD COUNCIL AT MINISTERIAL LEVEL, ALIGNING POLICIES FOR THE TRANSITION TO A LOW-CARBON ECONOMY 2 (2015).

[9] *Id.* at 51.

[10] GENERAL ELECTRIC, *supra* note 7, at 3.

[11] JA EDMONDS ET AL., GLOBAL ENERGY TECHNOLOGY STRATEGY: ADDRESSING CLIMATE CHANGE 39 (2007).

[12] G.A. Res. 70/1, at 1 (Oct. 21, 2015).

[13] *Id.* at 2.

[14] *Id.* at 6.

an integral part of sustainable development; among the seventeen goals of Agenda 2030, Goal 13 calls for actions to overcome climate change and its impact.[15] Agenda 2030 predicts that climate actions will drive sustainable development, and progress in sustainable development will help address climate change, e.g., through improving the global community's overall climate resilience and reducing GHG emissions.[16] Many other goals of Agenda 2030, from poverty eradication and ending hunger to conserving biodiversity and protecting oceans, also depend on the success of climate actions, and, therefore, the global development and deployment of cleantech innovation.

However, currently, there is significant global asymmetry in producing cleantech innovation. Patents, as tools that protect technical innovation, reflect a country's ability to innovate. According to empirical studies, developed countries currently dominate cleantech patent ownership. For example, Japan, the United States, Germany, the Republic of Korea, France and the United Kingdom lead the innovation and patenting of clean energy technologies.[17] Per an international survey, these five offices account for almost 85% of all patent applications in the clean energy technologies.[18] Such asymmetry was worse in the past; for example, in 1998, developed countries owned 95% of patents in key clean technologies.[19]

Because of such an asymmetry, at least since 1972, the global community has emphasized the voluntary transfer of clean technologies from developed countries to developing countries.[20] Such an emphasis has yet to become effective. Data show that most cleantech transfers have occurred between developed countries themselves; when cleantech transfers occurred between developed countries and developing countries, almost all transactions were between developed countries and emerging economies.[21] Studies have attributed

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[15] *Id*. at 14.

[16] *The Sustainable Development Agenda,* UNITED NATIONS (December 10, 2018), https://www.un.org/sustainabledevelopment/development-agenda/ [https://perma.cc/5HL4-YL44].

[17] Petro Roffe, *Patents and Clean Energy, Bridging the Gap between Evidence and Policy*, WORLD INTELLECTUAL PROPERTY OFFICE 27 (July 11, 2011), https://www.wipo.int/edocs/mdocs/mdocs/en/wipo_inn_ge_11/wipo_inn_ge_11_ref_t9.pdf.

[18] Petro Roffe, *Patents and Clean Energy, Bridging the Gap between Evidence and Policy*, WORLD INTELLECTUAL PROPERTY OFFICE 27 (July 11, 2011), https://www.wipo.int/edocs/mdocs/mdocs/en/wipo_inn_ge_11/wipo_inn_ge_11_ref_t9.pdf.

[19] *Generally* EUROPEAN COMMISSION, IS IPR A BARRIER TO THE TRANSFER OF CLIMATE CHANGE TECHNOLOGY? 18 (2009), https://trade.ec.europa.eu/doclib/html/143170.htm [https://perma.cc/3DEV-GY3B].

[20] *See* U.N. Conference on the Human Environment, *Report of the U.N. Conference on the Human Environment*, U.N. DOC. A/CONF.48/14/Rev. 1 (June 16, 1972); U.N. Conference on the Environment and Development, *Rio Declaration on Environment and Development*, U.N Doc. A/CONF.151/26/Rev.1 (Aug. 12, 1992); UNFCCC, *supra* note 3, at 11.

[21] Antoine Dechezleprêtre et al., *Invention and Transfer of Climate Change-Mitigation Technologies: A Global Analysis*, 5 REV. OF ENVTL. ECON. & POL'Y 109, 121-122 (2011)

the lack of cleantech transfer to most developing countries to two major reasons: first, developing countries' lack of capacities to absorb, adapt and implement foreign technologies, lack of market size and policy certainty and transparency, and lack of adequate intellectual property protection; and second, developed countries' failure to follow through on their commitment to providing aid.[22]

Meanwhile, the UNFCCC also emphasizes cleantech development and deployment (including application, diffusion, and transfer), instead of just international cleantech transfer. For example, the UNFCCC has its members commit to "promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices and processes" that are relevant for addressing climate change.[23] Furthermore, the 2015 Paris Agreement, an important UNFCCC milestone, states that the contracting parties "share a long-term vision on the importance of fully realizing technology development and transfer" so as to be able to respond to climate change and to reduce greenhouse gas emissions.[24] Thus, the commitment of the UNFCCC is on both cleantech development and deployment, instead of merely on international cleantech transfer to developing countries.

In light of the importance of both global cleantech development and deployment, this article explores an alternative to the emphasis on international cleantech transfer. Namely, developing countries should produce their own cleantech, hence, rely less on foreign cleantech, and make their own cleantech IP portfolios available for negotiating access to foreign cleantech. In the following discussion, this article demonstrates it is necessary for all countries to engage in cleantech innovation to address climate change and build sustainable development (Part I). Relying on available global cleantech innovation data, this article then reviews the current reality for domestic cleantech innovation by developing countries (Part II). Based on the observations from Parts I and II, this article then suggests a pathway for developing countries, especially the least developed countries, to build a domestic cleantech innovation system (Part III). The pathway includes three phases: international aid, mutually beneficial international cleantech cooperation, and domestic cleantech innovation. This includes a call for the global community to enable developing countries' eventual domestic innovation of cleantech through international aid and international cleantech cooperation. This article also proposes that a developing country builds its own cleantech innovation system by sending clear policy

(examining the cleantech flows among developed and developing countries during year 2000-2005). The emerging economies are the advancing economies among developing countries; they typically include China, India, Brazil, and South Africa.

[22] Joy Y. Xiang, *Addressing Climate Change: Domestic Innovation, International Aid and Collaboration*, 5 N.Y.U. JOURNAL OF INTELL. PROP. & ENT. LAW 1, 24, 54-55 (2016).

[23] The UNFCCC, art. 4.1.C.

[24] The Paris Agreement, art. 10.1-4.

signals to its private sector[25] and by using diverse innovation tools such as customized IPR, prizes, and innovation commons.

Before engaging in a detailed discussion, this article defines three terms that are fundamental to the discussion.

First, what is innovation? This article regards innovation as the practice or commercialization of a new idea or new way of doing things. A more specific definition treats innovation as the "implementation of a new or significantly improved product (good or service) process, new marketing method or a new organizational method in business practices, workplace organization or external relations."[26] Innovation can be the implementation of a fundamentally new product or process, as well as a minor improvement over existing products or processes.[27]

Conventional studies of innovations tend to focus on the economic dimension of innovation, and studies of innovations for sustainable development may cover the social, economic, and environmental dimensions of innovation.[28] This article will primarily focus on cleantech innovations, innovations that are likely to exert a positive impact on the environment.

Second, what is cleantech? Using the terms cleantech and "clean technology" interchangeably, this article regards them as being equivalent to or encompassing terms such as "green technology," "climate change technology," "climate technology," "environmentally friendly technology," and "environmentally sound technology." Cleantech can be diverse, including a wide range of technology sectors and markets.[29] Here, clean technology or cleantech means any technology that is capable of mitigating or adapting to climate change:[30] that is, "any equipment, technique, practical knowledge or

[25] In this article, private sector refers to the part of a national economy that is not owned or controlled by the government.

[26] Organisation for Economic Co-Operation and Development [OECD], *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, at 46 (2005).

[27] Lee Branstetter, Carnegie Mellon University, Peterson Institute for International economics, National Bureau of Economic Research, National Systems of Innovation and the Alternative Energy Innovation Challenge 2 (October 2014), http://unfccc.int/ttclear/events/2014_event5 [https://perma.cc/KZP8-5YYN].

[28] Bruno S. Silvestre & Diana Mihaela Țîrcă, *Innovations for Sustainable Development: Moving toward a Sustainable Future*, 208 JOURNAL OF CLEANER PRODUTION 325, 326-327 (2019).

[29] Joanna I. Lewis, *Managing Intellectual Property Rights in Cross-Border Clean Energy Collaboration: The Case of the U.S.-China Clean Energy Research Center*, 69 ENERGY POLICY 546, 547 (2014).

[30] The UNFCCC defines mitigation as "a human intervention to reduce the sources or enhance the sinks of greenhouse gases," and adaptation as "an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." UNFCCC, Glossary of Climate Change Acronyms and Terms (Dec. 10, 2018), https://unfccc.int/process-and-meetings/the-convention/glossary-of-climate-change-acronyms-and-terms [https://perma.cc/9WQD-QSTW].

skill to reduce GHG emissions or adapt to climate change."[31] Exemplary climate-change mitigation technologies include renewable energy technologies that utilize renewable energy sources — e.g., solar, wind, biomass, geothermal and hydro energy — to produce electricity, clean coal technologies that reduce GHG emissions from fossil fuel burning, and technologies to improve energy efficiency.[32] Exemplary climate change adaptation technologies include: technologies to produce seeds that can survive flooding caused by rising sea levels, irrigation technologies for resisting droughts, early-warning or defense systems for extreme weather, or technologies to address climate change-induced water stress or to adapt fisheries and aquaculture.[33] Cleantech also includes information technologies that are indispensable for managing environmental resources and cleantech operations, such as the smart electricity grid.[34]

Third, what constitute developing countries? The World Bank classifies countries as high-income, middle-income, and low-income, based on per capita national gross income.[35] This article utilizes the World Bank classification results and regards the classified high-income countries as developed countries, and the classified middle-income and low-income countries as developing countries.[36]

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[31] UNFCCC, *Enhancing Financing for the Research, Development and Demonstration of Climate Technology*, Rep. of Tech. Exec. Comm., at 6 (Nov. 2017), https://unfccc.int/ttclear/docs/TEC_RDD%20finance_FINAL.pdf [https://perma.cc/729E-BDF5].

[32] IPCC, *Climate Change 2001: Mitigation*, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, at 41 (July 2001).

[33] UNFCCC, Rep. on the Technologies for Adaptation to Climate Change, at 10, 16, 23 (2006).

[34] IPCC, *supra* note 32, at 98, 180

[35] World Bank Group [WBG], *How does the World Bank classify countries?* (2019), https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries [https://perma.cc/HT45-6RNZ].

[36] The UNFCCC regime has varied its classification of countries. For example, under the UNFCCC and the associated Kyoto Protocol, countries are grouped into Annex I and Annex II countries. "Annex I countries are industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States." "Non-Annex I Parties are mostly developing countries." "Annex II Parties consist of the OECD members of Annex I, but not the EIT Parties; are treated as developed countries. They are required to provide financial resources to enable developing countries to undertake emissions reduction activities under the Convention and to help them adapt to adverse effects of climate change. In addition, they have to take all practicable steps to promote the development and transfer of environmentally friendly technologies to EIT Parties and developing countries." UNFCC, *Parties and Observers* (July 29, 2019), https://unfccc.int/parties-observers [https://perma.cc/4QQU-AYL3]. The 2015 Paris Agreement, however, removed the UNFCCC country classifications, merely expecting developed countries, and others "in a position to do so," to continue to

I. DEVELOPING COUNTRIES NEED TO CREATE OWN CLEANTECH INNOVATION

Part I of the article will establish that in order to address climate change and build sustainable development effectively, developing countries must be able to effectively create their own cleantech, in addition to importing cleantech from other countries.

A. *Both Climate Action and Sustainable Development Require Domestic Cleantech Innovation*

Climate action and sustainable development are closely related. Proper climate action can enable sustainable development by providing a stable and healthy planet climate setting.[37] Otherwise, the negative effects arising from climate change can aggravate poverty, undercut sustainable development, and even endanger national security, especially in the least developed countries (LDCs).[38] Meanwhile, sustainable development can reduce GHG emissions and thus reduce further risks for climate change.[39] Going forward, integrating climate actions and sustainable development will be the trend.[40]

Both climate action and sustainable development require widespread development and deployment of cleantech. For example, of the seventeen sustainable development goals set up by Agenda 2030, SDG 7 demands access to clean and sustainable energy for all; SDG 9 mandates resilient infrastructure, sustainable industrialization and innovation; and SDG 13 calls for actions to addressing climate change.[41] All these goals point to the necessity of global-scale cleantech development and deployment.

Furthermore, local cleantech innovation is required for both sustainable development and sustainable climate action. The adoption and implementation of cleantech demand technology "appropriateness," which means "the degree to which technology fits its specific context of use…to be relatively low cost, locally made and serviced, and well-suited to their cultural, material, and ecological contexts."[42] In particular, climate adaptation efforts happen mostly at the local level — for example, how to respond to flooding and drought, how to

provide financial resources to help developing countries mitigate and increase resilience to climate change. *See* Paris Agreement, *supra* note 2, art. 9.

37 *See The Sustainable Development Agenda*, *supra* note 16, at 2.

38 *See id*. at 3, 54.

39 *See id*. at 37, 48.

40 *See id*. at 49.

41 G.A. Res. 70/1, *supra* note 12, at 2.

42 Dean Nieusma & Donna Riley, *Designs on Development: Engineering, Globalization, and Social Justice*, 2 ENGINEERING STUDIES 29, 32 (2010); Hans-Holger Rogner, *The Effectiveness of Foreign Aid for Sustainable Energy and Climate Mitigation* 9 (United Nations University World Institute for Development Economics Research Working Paper No. 2013/055, 2013).

address increased wildfires; this means that the cleantech employed needs to meet the requirements of the local context.[43]

Specifically, cleantech often needs to meet the climatic conditions of the area in which the cleantech is used. For example, cleantech developed for use in the dry Atacama Desert may not be as useful in humid Southeast Asia. Besides, the local implementation of cleantech also needs to satisfy the implementation priorities and capabilities of developing countries, which may differ much from those of developed countries. For example, a developing country's technology priority at a given time may not be specific cleantech such as smart grid technologies, but specific agricultural technologies to increase crop output in spite of frequent flooding; and its domestic manufacturers and engineers may not yet have the capacities to localize the smart grid technologies.[44] Studies have indicated that there are many cases of technologies transferred to Africa that were mismatched for the African context.[45]

Further, cleantech will likely benefit from leveraging local ecological knowledge and indigenous practices. Local ecological knowledge — knowledge accumulated over time about the geographic regions and the local environment — can help address climate change impact pragmatically, creatively, and holistically.[46] Meanwhile, traditional adaptation and mitigation measures combined with modern scientific knowledge can make climate action more effective.[47] For example, Mexico was recently able to utilize cacti, prevalent in that region, to produce biofuels, which are used to replace the gasoline used by cars.[48] African countries, such as Mozambique, have also created biofuels from local agricultural products such as coconuts, jatropha, and sugar cane.[49] Such local cleantech innovations are often cheaper and more efficient than importing, adapting, and implementing foreign cleantech.

Climate action and sustainable development both demand that cleantech innovation be appropriate for local contexts. Domestic cleantech innovation accomplishes these goals.

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[43] *See* Rogner, *supra* note 42, at 37, 48.

[44] *Id*. at 14, 17.

[45] SHIRIN ALAHI & JEREMY DE BEER, KNOWLEDGE & INNOVATION IN AFRICA: SCENARIOS FOR THE FUTURE 63 (Open A.I.R. Network, 2013).

[46] *See* Olga Laiza Kupika et al., *Local Ecological Knowledge on Climate Change and Ecosystem-Based Adaptation Strategies Promote Resilience in the Middle Zambezi Biosphere Reserve, Zimbabwe*, 2019 HINDAWI SCIENTIFICA 1, 2 (2019).

[47] Maxine Burkett, *Indigenous environmental knowledge and climate change adaptation, in* CLIMATE CHANGE AND INDIGENOUS PEOPLES 96, 98 (Edward Elgar 2013).

[48] *Mexico's 'green gold': The company powering cars with cactus juice*, CNN (Mar. 20, 2019, 9:38 AM), https://edition.cnn.com/2019/03/19/sport/cactus-power-car-formula-e-supercharged-vision-spt-intl/index.html [https://perma.cc/MJD2-FENZ].

[49] Fernando dos Santos & Simão Pelembe, *The State of Biofuel Innovation in Mozambique, in* INNOVATION & INTELLECTUAL PROPERTY: COLLABORATIVE DYNAMICS IN AFRICA 248 (Jeremy de Beer et al. eds., 2014).

B. *International Cleantech Transfer Alone is not Enough*

A common reaction to the suggestion of domestic cleantech innovation by developing countries is that international cleantech transfer — e.g., from developed countries to developing countries — should be able to provide the cleantech developing countries need. Proponents of international cleantech transfer suggest that developing countries do not have the capacity for advanced cleantech R&D.[50] This is likely a correct assessment regarding some developing countries; for example, many of the LDCs may not have resources to invest in advanced cleantech R&D. Proponents of international cleantech transfer argue that because developed countries already possess the majority of the existing cleantech, developing countries should buy cleantech from developed countries, rather than invent their own. These are reasonable propositions, which may explain why international cleantech transfer has been an emphasis of the global community since the 1970s.[51]

Approximately 85% of global R&D investments occur in developed countries.[52] Furthermore, developed countries own at least 80% of the patents of existing key clean technologies.[53] Because developed countries own the majority of the existing clean technologies, the transfer of clean technologies from developed countries to developing countries seems an obvious solution

[50] UNFCCC, *Enhancing Financing for the Research, Development and Demonstration of Climate Technology*, *supra* note 31, at 18-19.

[51] *See* U.N. Conference on the Human Environment, *supra* note 20, at 5; U.N. Conference on the Environment and Development, *supra* note 20, at 2; UNFCCC, *supra* note 3, at arts. 4.5, art. 4.7.

[52] UNESCO, How Much Does Your Country Invest in R&D? (June 2019), http://uis.unesco.org/apps/visualisations/research-and-development-spending/ [https://perma.cc/4MGQ-9PYE] (stating that the 85% figure is derived from the sum of available data on R&D spending from high-income countries divided by the sum of available data on global R&D spending in 2017).

[53] THOMAS FRANKLIN AND KATE GAUDRY, INDUSTRY-FOCUSED PATENTING TRENDS 42 (2019) (showing that the U.S., EU, Japan and South Korea together each year took up at least 80% of cleantech patent filings in the U.S. from 2011 to 2018), https://www.kilpatricktownsend.com/Insights/Publications/2019/4/PatentingTrendsStudy [https://perma.cc/FQK2-BF4W]; *see also* EUROPEAN COMMISSION, *supra* note 19, at 4; U.N. ENVIRONMENT PROGRAMME ET AL., PATENTES Y ENERGÍA LIMPIA: CERRANDO LA BRECHA ENTRE EVIDENCIA Y POLÍTICA [PATENTS AND CLEAN ENERGY: CLOSING THE GAP BETWEEN EVIDENCE AND POLICY] 4, 7 (2010); U.N. ENVIRONMENT PROGRAMME & EUROPEAN PATENT OFFICE, PATENTS AND CLEAN ENERGY TECHNOLOGIES IN AFRICA 7 (2013); U.N. ENVIRONMENT PROGRAMME & EUROPEAN PATENT OFFICE, PATENTS AND CLIMATE CHANGE MITIGATION TECHNOLOGIES IN LATIN AMERICA AND THE CARIBBEAN 7 (2014). These three patent filing studies of climate change mitigation technologies from 1980 to 2007 reveal that the U.S., the U.K., Germany, France, Japan and South Korea dominated the number patent filings; China rose to account for 25% of such patent filings in 2010; and African countries accounted for less than 1%, and Latin American and Caribbean countries less than 3% such patent filings.

and, hence, has been a focus of the global effort in addressing climate change via clean technologies. Accordingly, under the stipulations of international treaties such as the UNFCCC and the WTO Agreement on Trade-Related Aspects of Intellectual Property Rights ("TRIPS Agreement"), developed countries have committed to facilitate technology transfer to developing countries, especially the LDCs.[54] However, the effectiveness of these treaties in enabling international cleantech transfer has limited.

According to the UNFCCC, developed countries bear the largest historical and current share of global GHG emissions, whereas developing countries have a relatively low per capita emission, although their share of the global GHG emissions will grow due to development needs.[55] The UNFCCC hence requires governments of developed countries to take "all practicable steps to promote, facilitate and finance, as appropriate, the transfer of or access to environmentally sound technologies and know-how" to other countries, particularly developing countries.[56] The UNFCCC also conditions developing countries' effectiveness in addressing climate change on the effectiveness of developed countries in fulfilling the above-mentioned obligation of facilitating and financing the transfer of or access to cleantech.[57] However, such a requirement has no teeth because the UNFCCC lacks any mechanism to enforce the requirement on developed member countries: the implementation of the requirement is up to each country's voluntary compliance.[58]

The TRIPS Agreement, entered into force eight months after the UNFCCC agreement, also requires developed country governments to promote and encourage technology transfer to the LDC members.[59] Specifically, the TRIPS Agreement mandates governments of developed countries to "provide incentives to enterprises and institutions in their territories" so as to promote and encourage technology transfer to the LDCs in order to "enable them to create a sound and viable technological base."[60] In the WTO forum, however, a WTO member may hold another member responsible for its non-compliance of a WTO requirement via the WTO dispute resolution system.[61] If a WTO member fails to comply, that member may need to change the non-complying law, pay

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[54] *Agreement on Trade-Related Aspects of Intellectual Property Rights*, Apr. 15, 1994, Marrakesh Agreement Establishing the World Trade Organization, Annex 1C, 33 I.L.M. 81, 1869 U.N.T.S. 299 [hereinafter "TRIPS Agreement"], art. 66.2; UNFCCC, *supra* note 3, at arts. 4.1, 4.3, 4.7.

[55] UNFCCC, *supra* note 3, preamble ¶ 3.

[56] *Id*. art. 4.5.

[57] *Id*. art. 4.7.

[58] *Id*. art. 4.10.

[59] TRIPS Agreement, *supra* note 54, art. 66.2.

[60] *Id*.

[61] World Trade Organization [WTO], *Dispute Settlement (*Dec. 10, 2018), https://www.wto.org/english/tratop_e/dispu_e/dispu_e.htm [https://perma.cc/2A4D-64S9].

compensation, or suffer retaliation.[62] However, the WTO dispute resolution system currently is in limbo as the appellate body of the system went into dysfunction as of December 2019.[63]

Despite the emphasis of international cleantech transfer in international law, the evidence shows that international cleantech transfer alone produces inadequate results. First, actual international transfer of cleantech to developing countries has been limited. Data shows that international cleantech transfer has primarily occurred between developed countries (e.g., 73% of the overall exported inventions), although exports of cleantech inventions from developed countries to emerging economies – such as China, Brazil, and India – are growing rapidly (e.g., 22% of the overall exported inventions).[64] Meanwhile, cleantech transfer transactions from developed countries to developing countries which are not emerging economies are very rare.[65] For example, of the 384 programs submitted by developed countries demonstrating their efforts to fulfill their technology transfer obligations under the TRIPS Agreement, only 42 (11%) that targeted a WTO least-developed country (LDC) member qualified as aid that encouraged technology transfer.[66]

Second, the sole reliance on international cleantech transfer alone may place developing countries in a perpetual state of dependence on the output of cleantech from developed countries. Not only does this likely going go against the goals of developing countries, but also, even a willing reliance on international cleantech transfer by developing countries will demand local capability to adapt and implement foreign cleantech. This includes institutions, infrastructure and human capital needed in order to attract, adapt, and implement

[62] However, no WTO developing member countries have complained via the WTO dispute resolution mechanism that a developed member country failed to fulfill the technology transfer requirement. As of April 20, 2019, the WTO dispute settlement mechanism has received only one complaint concerning technology transfer: the European Union's complaint concerning China's legal measures regarding transfer of foreign technologies into China. *See* Request to Join Consultations, *China – Certain Measures on the Transfer of Technology*, WTO Doc. WT/DS549/6 (Jan. 21, 2019).

[63] Vineet Hegde, *As WTO's Dispute Settlement Body Dies a Dysfunctional Death, What Comes Next?,* THE WIRE (Dec 11, 2019), https://thewire.in/trade/wto-dispute-settlement-body-defunct.

[64] Antoine Dechezleprêtre et al., *Invention and Transfer of Climate Change-Mitigation Technologies: A Global Analysis*, 5 REVIEW OF ENVIRONMENTAL ECONOMICS AND POLICY 109, 121-122 (2011), (by examining the cleantech flows among developed and developing countries during year 2000-2005).

[65] *See* Suerie Moon, ICTSD Programme on Innovation, Technology and Intellectual Property, *Meaningful Technology Transfer to the LDCs: A Proposal for a Monitoring Mechanism for TRIPS Article 66.2* 1, 5 (2011), https://www.ictsd.org/sites/default/files/downloads/2011/05/technology-transfer-to-the-ldcs.pdf [https://perma.cc/U5SG-5DUL].

[66] *Id*.

foreign cleantech.[67] Developed countries have critiqued developing countries for lacking such resources.[68] Moreover, international aid has yet to catch up to aid developing countries in building up such capacities.[69]

Third, as discussed in Part I.A, both climate acts and sustainable development benefit from local cleantech that leverages traditional knowledge, indigenous practices, and understanding of the local climate and ecological environment. Hence, relying on voluntary cleantech transfer from developed countries to developing countries alone is lacking and will likely be insufficient for sustainable development and climate action. The global community must examine alternatives while continuing efforts to improve the state of international cleantech transfer.

The limited amount international cleantech transfer and high prices of foreign cleantech have already forced developing countries to consider alternatives. To obtain free or cheap access to cleantech, developing countries have suggested removing IPR protection on existing or future cleantech or issuing compulsory licenses for IPR-protected cleantech.[70] The author has explored these proposals in a previous article and has concluded that this is not an optimal solution.[71] This article focuses on another alternative: developing countries enhance their own capability to create domestic cleantech innovation with the help of the global community.

II. Reality Check: Current Domestic Cleantech Innovation by Developing Countries

This part of this article explores what is necessary to build domestic innovation of cleantech, and then assesses how developing countries are performing currently in domestic cleantech innovation, leveraging available data provided by international surveys. The examination and assessment in this part of this article pave the way for this article's proposal in Part III. This article presumes the main actor for enabling domestic cleantech innovation would be a national government or a local government covering a specific jurisdiction.

A. *What Takes to Build Domestic Cleantech Innovation*

Various matrices are available for measuring what takes to build a cleantech innovation system. For instance, to assist UNFCCC member countries with the pressing need to accelerate and strengthen cleantech innovation, the Technology

[67] Council for Trade-Related Aspects of Intellectual Property Rights, *Item 11 Contribution of Intellectual Property to Facilitate the Transfer of Environmentally Rational Technology*, WTO Doc. IP/C/M/76/Add.1 (June 11, 2014).

[68] *Id.*

[69] *See* discussion *infra* Sections III.B.1.

[70] Communication from Ecuador, *Contribution of Intellectual Property to Facilitating the Transfer of Environmentally Rational Technology*, WTO Doc. IP/C/W/585 (Feb. 27, 2013).

[71] Joy Y. Xiang, *IPR Management in International Cleantech Cooperation*, 32 Geo. Envtl. Law Rev. (2019).

Executive Committee of the UNFCCC provides six recommendations.[72] First, "[t]o prioritize resources (human, institutional, and financial) for cleantech innovation efforts, in accordance with a country's needs, priorities, and capacities."[73] Second, "[t]o enhance public and private partnership in the research, development, and demonstration (RD&D) of cleantech by increasing government cleantech expenditure and providing a clear policy signal of a long-term commitment to act on climate change."[74] Third, "[t]o strengthen national systems of innovation and enabling environments, including through market creation and expansion and capacity building."[75] Fourth, "[t]o enhance existing and build new collaborative initiatives for climate technology innovation, including for sharing expertise, good practices and lessons learned."[76] Fifth, "[t]o create an inclusive innovation process that involves all key stakeholders, facilitating the incorporation of diverse and relevant expertise, knowledge and views and generating awareness of the benefits and impacts."[77] Lastly, "[t]o acknowledge and protect indigenous and local knowledge and technologies and incorporate them into their national innovation systems.[78] This article considers the six recommendations can be merged into two by including the first recommendation under the second, and the fourth, fifth, and sixth recommendations under the third. In sum, the UNFCCC Technology Executive Committee essentially suggests that UNFCCC member countries increase government expenditure on cleantech RD&D in order to send a clear policy signal to the private sector regarding their governments' long-term commitment for climate action, and to enable and strengthen national innovation systems.

Another exemplary innovation matrix embraces a combination of technology-push policies for creating new technology and market-pull policies for generating market demand for technologies.[79] The technology-push policies suggested include: capacity building, infrastructure development, government-funded demonstration projects, public-private partnerships to share R&D risk, government-sponsored R&D, and tax credits to invest in R&D.[80] The market-pull policies include, for example, product standards, cap-and-trade,[81]

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72 2017 Joint Annual Report, *supra* note 4, at 11.

73 *Id.*

74 *Id.*

75 *Id.*

76 *Id.*

77 *Id.*

78 *Id.*

79 MATTHEW BATESON, INNOVATION AND PARTNERSHIP MODELS 11 (WBCSD 2011), https://www.wipo.int/edocs/mdocs/mdocs/en/wipo_inn_ge_11/wipo_inn_ge_11_ref_t20.pdf [https://perma.cc/7EC6-3R9E].

80 *Id.*

81 CAP AND TRADE BASICS, CENTER FOR CLIMATE AND ENERGY SOLUTIONS (Apr. 20, 2019), https://www.c2es.org/content/cap-and-trade-basics/ [https://perma.cc/U9SF-P2DC].

regulations requiring the use of best available technology, feed-in tariffs,[82] portfolio standards, public procurement, and IPR protection.[83] This innovation matrix illustrates a common idea for building an innovation system, the innovation pipeline concept. As the name suggests, innovation is viewed as a pipeline with inputs on one end of the pipeline processed to produce outputs at the other end of the pipeline. The concept presumes that good input to innovation will result in good innovation outputs.[84] The goal of input to innovation is to turn useful research outcome into an economic asset (e.g., an IP asset) and to facilitate the commercialization and distribution of the useful research outcome.[85] In the above innovation matrix example, the technology-push policies are the input to innovation, pushing for the generation of useful research outcomes; the market-pull policies are more on the output of innovation, pulling for the commercialization of the useful research outcomes.[86]

A different innovation matrix, the cleantech innovation matrix compiled by the Global Cleantech Innovation Index (GCII), adopts the innovation pipeline concept as well.[87] The GCII conducts periodical global surveys measuring how a country has built up its domestic cleantech innovation system in order to enable the emergence of entrepreneurial cleantech companies over the upcoming ten years.[88] The GCII establishes a cleantech innovation matrix to measure the performance of a country's cleantech innovation system. Integrating measurements from multiple global indexes and surveys, the GCII cleantech innovation matrix is comprehensive and inclusive. For example, the 2017 GCII clean innovation matrix incorporated input from seventeen global surveys concerning innovation, entrepreneurship, cleantech, and intellectual property.[89]

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[82] *What are Feed-in-Tariff?*, FEED-IN TARIFF, https://www.fitariffs.co.uk/fits/ [https://perma.cc/828D-N7HM].

[83] Bateson, *supra* note 79, at 8.

[84] *Id*.

[85] Cynthia Cannady, *Access to Climate Change Technology by Developing Countries: A Practical Strategy*, ICTSD's Programme on IPRs and Sustainable Development, Issue Paper No. 25, INTERNATIONAL CENTRE FOR TRADE AND SUSTAINABLE DEVELOPMENT [ITCSD] (2009), https://www.ictsd.org/sites/default/files/downloads/2009/11/access-to-climate-change-technology-by-developing-countries-cannady.pdf [https://perma.cc/8GV3-CXQ9].

[86] Bateson, *supra* note 79.

[87] GCII came about with the support of United Nations Industrial Development Organization (UNIDO) and the Global Environmental Facility (GCF). Started in 2012, it seems to be the only study on what economic, social and environmental conditions cultivate the emergence of cleantech innovation. *See Global Cleantech Innovation Index 2017* – Global Cleantech Innovation Programme (GCIP) Country Innovation Profiles 7 (2017), http://info.cleantech.com/rs/151-JSY-946/images/Global_Cleatech_Innovation_Index_2017_FINAL.pdf [https://perma.cc/AE5Y-HEBR] [hereinafter GCII 2017].

[88] *Id*.

[89] For example, (1) INSEAD, Cornell University, WIPO, GLOBAL INNOVATION INDEX, 2016; (2) Global Entrepreneurship Research Association (GERA), GLOBAL

Therefore, the article uses the GCII cleantech innovation index as a base to assess whether developing countries have capacities to build domestic cleantech innovation.[90]

The GCII cleantech innovation matrix measures a country's cleantech innovation system in terms of input to cleantech innovation and output of cleantech innovation. Specifically, there are two groups of indicators for assessing a country's ability to induce the creation of innovation:

general innovation drivers and cleantech-specific innovation drivers.[91] The GCII cleantech innovation matrix also provides two levels of indicators for assessing a country's ability to produce cleantech innovation – i.e., evidence of emerging cleantech innovation and evidence for commercializing cleantech innovation.[92] Figure 1 below provides a graphic outline of the top-level indicators in the GCII cleantech innovation matrix.[93]

ENTREPRENEURSHIP MONITOR, 2016; (3) IEA, ENERGY R&D DATABASE, 2015; (4) IEA, Tracking Clean Energy Progress, 2015; (5) U.N., Gross National Expenditure on R&D 2013-14; (6) REN-21, Renewables 2016 Global Status Report; (7) World Bank, State and Trends of Carbon Pricing, 2016; (8) OECD & Bloomberg Philantrophies, Green Bonds, Policy Perspective, 2015; (9) Ernst & Young, RENEWABLE ENERGY COUNTRY ATTRACTIVENESS INDEX, 2016; (10) Cleantech Group, Global Cleantech 100, 2014 – 2016; (11) OECD, Patent Cooperation Treaty database, 2013; (12) U.N., Comtrade Import/Export data, 2014-2016; (13) BP, STATISTICAL REVIEW OF WORLD ENERGY, 2016; (14) IRENA, RENEWABLE ENERGY AND JOBS ANNUAL REVIEW, 2016; (15) Cleantech Group, FTSE, Ardour and WilderHill indices of publicly traded cleantech companies, 2016; (16) Cleantech Group, Venture Capital Investment, i3 data, 2014 – 2016; (17) World Bank indicators, 2016. *See id*. at 12.

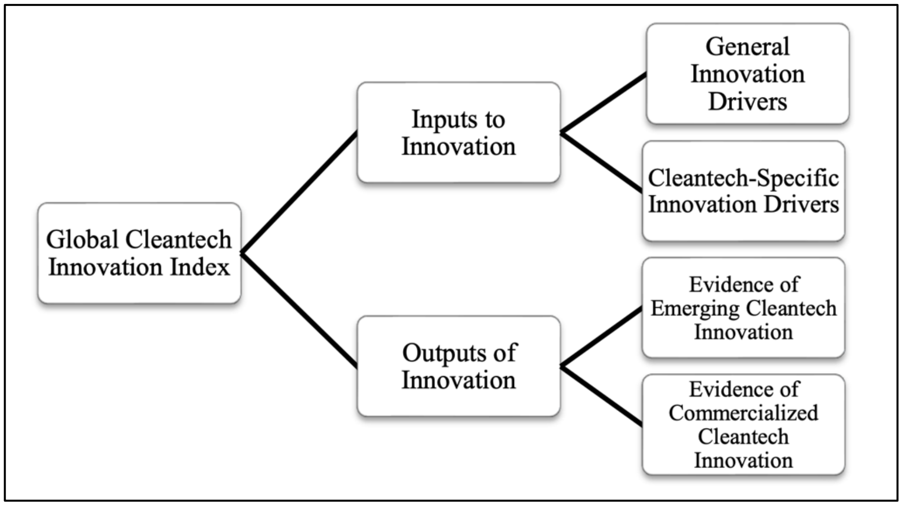
90 However, the GCII cleantech innovation matrix is just one of the ways to measure a cleantech innovation system; it is by no means the only way.

91 GCII 2017, *supra* note 87.

92 *Id*.

93 Recreated from GLOBAL CLEANTECH INNOVATION INDEX 2017 – GLOBAL CLEANTECH INNOVATION PROGRAMME [GCIP] COUNTRY INNOVATION PROFILES 72 [hereinafter GCIP 2017], *available at* https://i3connect.com/gcii/reports.

Figure 1. Global Cleantech Innovation Index



Each of the indicators may host one or more parameters. Next, the article provides a summative explanation of these indicators and their parameters, before evaluating the performance of developing countries in view of these indicators.

1. The Input Measures for Cleantech Innovation

The GCII clusters indicators for creating cleantech innovation into general innovation drivers and cleantech-specific innovation drivers.[94]

a. *General Innovation Drivers*

The general innovation drivers measure a country's underlying economic, institutional, and social frameworks for a domestic innovation system in general, not specific to cleantech.[95] In GCII, general Innovation drivers include general innovation inputs and entrepreneurial culture.

[94] GCII 2017, *supra* note 87, at 46.

[95] *Id*. at 18. The indicators on general innovation inputs come from the Global Innovation Index, which is product of collaboration between Cornell University, INSEAD business school, and WIPO. *See* THE GLOBAL INNOVATION INDEX 2016, WIPO (2016) [hereinafter Global Innovation Index 2016], https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2016.pdf [https://perma.cc/VN9C-8GNQ].

i. General Innovation Inputs

General innovation inputs are indicators that are important to a country's innovation ability in general, which include institutions, human capital and research ability, infrastructure, and market and business sophistication.[96]

The institutions indicator focuses on the political, regulatory, and business environments of a country.[97] The political environment parameter captures perceptions of the likelihood that a government might be destabilized and the quality of public and civil services, and policy formulation and implementation in a country.[98] The regulatory environment parameter captures perceptions on, e.g., the ability of a government to formulate and implement cohesive policies that promote the development of the private sector, and evaluates the extent to which the rule of law prevails (in aspects such as contract enforcement, property rights, the police, and the courts) in a country.[99] The business environment parameter indicates the ease with which the public may start a business, resolve insolvency, and pay taxes.[100]

The human capital and research ability indicator captures the level and standard of education and research activity in a country.[101] Education systems and research institutes (public or private) are essential institutions for building an innovation system because they are prime determinants of the innovation capacity of a country.[102]

The infrastructure indicator refers to information and communication technologies (ICTs), general infrastructure, and ecological sustainability.[103] The ICTs parameter measures the existence of good and ecologically friendly communication, transport, and energy infrastructures. The general infrastructure parameter measures, for example, the average electricity output per person, logistics performance, and gross capital formation.[104]The ecological sustainability parameter measures, for example, efficiency in the use of energy and the number of environmental management systems issued.[105] Infrastructure is a

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[96] GCII 2017, *supra* note 87, at 50.

[97] *Id*.

[98] *Id*. at 51.

[99] *Id*.

[100] *Id*.

[101] *Id*. at 52.

[102] Branstetter, *supra* note 27, at 35.

[103] Global Innovation Index 2016, *supra* note 95, at 50.

[104] Such as land improvements, plant, machinery, and equipment purchases, the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. *See id*. at 53.

[105] *Id*.

public good that private sectors would under produce, and, thus, necessitates substantial government involvement.[106]

The market sophistication indicator measures the availability of credit and the environment that enables investment, access to the international market, competition, and market scale.[107] The business sophistication indicator, meanwhile, assesses how conducive firms are to innovation activities.[108] Innovation activities manifest through, for example, employment activities in knowledge-intensive services, the availability of formal training at the firm level, R&D performed by a business enterprise, and the percentage of total gross expenditure on R&D that is financed by the business enterprise.[109]The business sophistication indicator also measures innovation linkages such as collaborations between businesses and universities on R&D, the prevalence of well-developed and deep industrial clusters, the level of gross R&D expenditure financed from abroad, and the number of joint ventures and strategic alliances.[110]

ii. Entrepreneurial Culture

In GCII, entrepreneurial culture gages a society's positive attitudes toward entrepreneurship and volume of early-stage entrepreneurial activity.[111] A society's positive attitudes toward entrepreneurship is reflected through factors such as the extent to which a society values entrepreneurship as a good career choice, whether entrepreneurs have high societal status, and the extent to which media attention to entrepreneurship contributes to the development of a positive entrepreneurial culture.[112] The volume of early-stage entrepreneurial activity is measured, for instance, by the number of entrepreneurs involved in setting up a

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[106] *See, e.g.*, Joshua D. Sarnoff, *Government Choices in Innovation Funding,* RESEARCH HANDBOOK ON INTELLECTUAL PROPERTY AND CLIMATE CHANGE 202 (Joshua D. Sarnoff ed., 2016).

[107] Global Innovation Index 2016, *supra* note 95, at 53.

[108] *Id*. at 53.

[109] This indicator, in addition to providing a glimpse into the gender labor distributions of nations, offers more information about the degree of sophistication of the local human capital currently employed. *See id.*

[110] *Id*. at 54.

[111] GCII 2017, *supra* note 87, at 46. GCII 2017 measures the Entrepreneurial Culture indicator based on data from the Global Entrepreneurship Monitor 2016. Global Entrepreneurship Monitor claims to be the foremost global study of entrepreneurship. A joint effort between Boston College and London Business School since 1999. It collects data on entrepreneurial behavior and attitudes of individuals and the national context and how that impacts entrepreneurship. *See* Global Entrepreneurship Research Assoc., *What is GEM?, How Does Gem Work?,* GLOBAL ENTREPRENEURSHIP MONITOR (Apr. 12, 2019), [https://perma.cc/22JB-6MT6].

[112] GLOBAL REPORT 2016/2017, GLOBAL ENTREPRENEURSHIP MONITOR 15 (Apr. 12, 2019) https://www.gemconsortium.org/report [https://perma.cc/8B2K-CXG7] [hereinafter Global Entrepreneurship Monitor 2016].

business and the number of entrepreneurs who are an owner or a manager of a new business (less than 3.5 years old).[113]

b. *Cleantech-Specific Innovation Drivers*

In the GCII cleantech innovation matrix, cleantech-specific innovation drivers include: cleantech-friendly government policies, government R&D expenditure in cleantech sectors, cleantech start-ups' access to private finance, country-attractiveness in term of renewable energy infrastructure, and the number of cleantech industry cluster programs and initiatives.[114]

Turning to government policies, GCII compiles cleantech-friendly government policies into eight categories. These include: 1) carbon tax and carbon market, 2) clean energy tax incentives and tax incentives specifically for clean technology companies, 3) green bonds, government-backed or –owned green investment banks, green investment funds, 4) government investment, loans, or grants for cleantech,[115]5) transportation obligation and transportation efficiency or emission standards, 6) renewable energy standard and feed-in tariffs, electric utility quota obligation, 7) government tendering or green procurement, and 8) research institutes or government-supported university programs for cleantech.[116]According to the GCII 2017 survey, performances vary greatly across the world; some countries have cleantech-friendly government policies in all the eight categories, while other countries have such policies in only two or three of the eight categories.[117]

The indicator of government R&D expenditure in cleantech sectors measures a country's total budget for cleantech R&D as a proportion of GDP.[118] The cleantech start-ups' access to private finance indicator measures the number of cleantech investors and cleantech-focused funds recently raised in a country.[119] Country-attractiveness of renewable energy infrastructure looks at factors such as national renewable energy markets, renewable energy infrastructures and their suitability for wind, solar, biomass and other renewable energy technologies.[120] Cleantech cluster programs and initiatives assesses a country's economic initiatives supporting the cleantech industry as a portion of GDP, and the number of industry associations and physical clusters for cleantech development and deployment.[121]

[113] *Id*. at 16.
[114] GCII 2017, *supra* note 87, at 46
[115] GCIP 2017, *supra* note 93, at 69.
[116] *Id*.
[117] *See generally* GCII 2017, *supra* note 87.
[118] GCII 2017, *supra* note 87, at 46.
[119] *Id*.
[120] *Id*.
[121] *Id*.

2. The Output Measures for Cleantech Innovation

The GCII compiles the indicators for measuring the output of domestic cleantech innovation into two groups: evidence on emerging cleantech innovation and evidence on cleantech innovation commercialization.[122] Evidence on emerging cleantech innovation measures early-stage private investment in cleantech, the generation of high-impact cleantech companies, and the filing of cleantech patent applications.[123] Evidence on cleantech innovation commercialization determines the volume of cleantech imports and exports, consumption of renewable energy, late-stage investment on cleantech, listed cleantech companies, and employees engaging in cleantech-related work.[124]

B. *How are Developing Countries Performing Currently*

Systematic studies of developing countries' cleantech innovation systems are scarce. The aforementioned GCII focuses its study on G20 countries,[125] as data on them have been easy to gather. The GCII selects another twenty countries in the G20 geographic regions to supplement its assessment. Of these additional twenty countries, ten are not high-income countries, hence satisfying this article's definition of developing countries in the Introduction section.[126] Altogether, the GCII surveys forty countries (GCII countries). However, GCII made no selection of low-income countries, as data for these countries were either not available or were difficult to collect or measure against the GCII indicators. According to the GCII conductor, measuring low-income countries' domestic cleantech innovation systems "would have to rely on too much estimation."[127]

In 2017, a supplemental study extended the 2017 GCII survey to the eight developing countries involved in the Global Cleantech Innovation Programme (GCIP).[128] This article will refer to this supplemental study as GCIP 2017, and the base study as GCII 2017. GCII covers three of the eight GCIP partnering developing countries – India, South Africa, and Turkey; countries added by the GCIP study are Armenia, Malaysia, Morocco, Pakistan, and Thailand.[129] The GCII 2017 and GCIP 2017 studies together now offer data on fifteen developing countries.[130] The GCIP 2017 survey provides more detailed data on each of the

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[122] *Id.*

[123] *Id.*

[124] *Id.*

[125] *G20 Members*, G20 TURKEY (last visited October 19, 2019), http://g20.org.tr/about-g20/g20-members/ [https://perma.cc/Q6AB-65VW].

[126] GCII 2017, *supra* note 87.

[127] Emails from Cleantech Group, the survey conductor of GCII 2017, and GCIP 2017 (Jan. 2019) (on file with the author).

[128] GCIP 2017, *supra* note 93.

[129] *Id.*

[130] *Id. See also* GCII 2017, *supra* note 87.

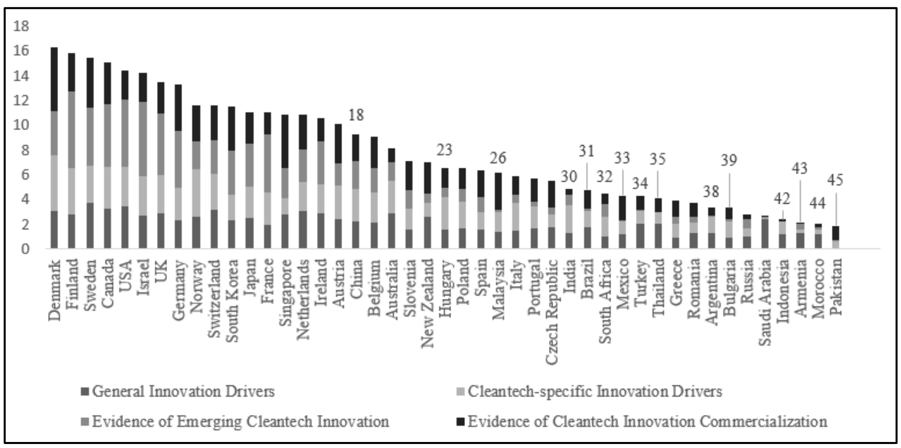
eight countries than the GCII 2017 survey does.[131] According to the country classifications provided by the World Bank,[132] ten of these fifteen developing countries are upper middle-income countries—Argentina, Bulgaria, Brazil, China, Hungary, Malaysia, Mexico, South Africa, Thailand, Turkey; the other five are lower middle-income countries: Armenia, India, Indonesia, Morocco, Pakistan.

1. The Overall Assessment

This article combines the data from both the GCII 2017 and the GCIP 2017 to examine the performance of the fifteen developing countries covered by the combination. As discussed in Part A, the strength of the studies lies in its integration of criteria and data from multiple global surveys (17 global surveys in 2017); the of studies' weakness, at least for the purpose of this article, is absence of data on the LDCs. Consequently, the assessment on developing countries are data on countries in the lower and upper middle-income countries.

Figure 2 below captures the relative rankings of the forty-five countries surveyed by the 2017 GCII and the GCIP 2017, based on compilation of data from both surveys. The number above a developing country indicates this developing country's position in the overall rankings of the forty-five countries.

Figure 2. Overall Rankings



As shown in Figure 2 above, the fifteen developing countries' cleantech innovation performances generally fall toward the lower half of the rankings, except for China which is ranked eighteen of the forty-five countries surveyed. The developing countries overall have below-average input to innovation in

[131] GCIP 2017, *supra* note 93; GCII 2017, *supra* note 87.

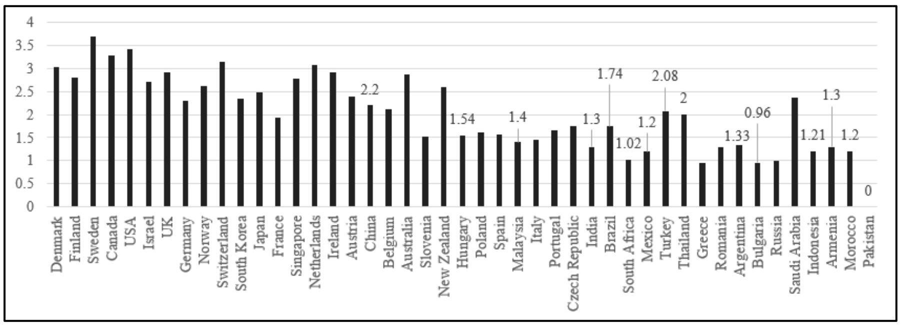
[132] WORLD BANK COUNTRY AND LENDING GROUPS, WORLD BANK, (last visited April 30, 2020) https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups [https://perma.cc/VZ6A-8BNB].

general and to cleantech specifically. As a result, these countries have a below-average output for cleantech innovation as well.

Comparing the performance of the G20 countries with the fifteen developing countries in the measurements of the indicators for inputs to innovation reveals the following differences.

Figure 3 below illustrates the forty-five countries' performance in general innovation drivers. The datum above a developing country indicates the developing country's overall score for the measurements in general innovation drivers.

Figure 3. General Innovation Drivers



As shown in Figure 3 above, the top ten leading countries in general innovation drivers are all located in North America and Europe (including Australia). Countries such as Sweden, the United States, and Switzerland possess sophisticated government institutions, market capacity, and educational system spending, which creates high general innovation inputs as well as a high perception of entrepreneurship opportunities.[133]

Developing countries score in the middle and lower half of the rankings for general innovation drivers, with China leading at ranking at twenty-first. The developing countries all score lower than average on the general innovation input indicators. Therefore, these countries must upgrade general capacities for innovation, namely by strengthening institutions, human capital and research ability, infrastructure, and market and business sophistication.

GCIP 2017 observes that all eight GCIP partnering developing countries could benefit from better coordination between domestic entities that provide input to innovation.[134] Such coordination happens among government agencies that are responsible for managing innovation-promoting initiatives and policies. The GCIP 2017 also encourages improved coordination between government

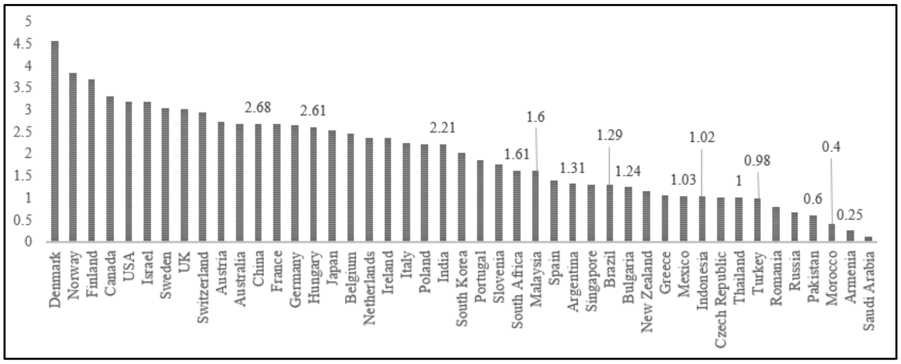
[133] GCII 2017, *supra* note 87, at 18.
[134] GCIP 2017, *supra* note 93, at 7.

agencies and the private sector, because robust government policies are often not received with strong support from the private sector.[135]

Emerging economies such as Brazil scored higher at the early-stage entrepreneurship activities. This trend is likely due to the large market size of the emerging economies since their scores on general innovation inputs are still lower than average.[136]

Figure 4 below shows the forty-five countries' performance in providing cleantech-specific innovation support. The datum above a developing country reflects the overall score the developing country possesses for cleantech-specific innovation drivers.

Figure 4. Cleantech-Specific Innovation Drivers



All fifteen developing countries show some government support for the cleantech sector, which typically focuses on overarching cleantech-friendly policies. However, there is a large disparity between leading and laggard countries.[137] For example, of the eight GCIP partnering developing countries surveyed, South Africa provides a good overarching cleantech supportive policy environment, with established policies in all the eight cleantech-friendly policy categories tracked by the GCII.[138] In contrast, Turkey, Pakistan, Morocco have satisfied only three of the eight categories, and Armenia only two.[139]

Meanwhile, in the eight GCIP partnering developing countries, universities' cleantech research activities are often detached from the private sector; the latter often does not translate universities' cleantech research activities into commercial products.[140] None of the developing countries showed significant numbers of cleantech-related industrial clusters. In these countries, the

135 *Id.*
136 *Id.* at 19.
137 *Id.* at 13
138 *Id.* at 52.
139 *Id.* at 18-72.
140 *Id.* at 8.

connection between innovators and potential investors or industrial partners has not been strong enough to facilitate the scaling up of cleantech startups.[141]

It is noteworthy that China ranks at position thirteen here, scoring higher than France, Germany, and Japan. This likely a result of China's attractiveness as an investment destination for renewable energy and its relative strength in cleantech public funding.[142]

2. Case Studies

To illustrate the performance of developing countries in domestic cleantech innovation in more detail, this article will focus on the domestic cleantech innovation performances of India, Turkey, and Morocco. These three countries were chosen due to their ranking in both the GCII 2017 and GCIP 2017, economic development status (e.g., income level), and the availability of data on domestic cleantech innovation systems (e.g., Pakistan and GCII developing countries are not selected because of incomplete or less comprehensive data).

a. *India*

Turning to India first, the country's general innovation capacity is low, cleantech-specific government input is high, and output for cleantech innovation is low.[143] India scores below the mean on all measurements in the GCIP 2017 survey, except for the above-average performance in cleantech-specific innovation drivers.[144]

India's score on general innovation drivers is lower than major emerging economies—all BRICS countries[145], with the exception of Brazil.[146] However, Indian society hosts a positive view of entrepreneurship and is optimistic about perceived entrepreneurial opportunities. India has a high score in early-stage entrepreneurial activity as well.[147]

India's strong performance for cleantech-specific innovation is likely primarily due to its attractiveness as a renewable energy investment destination.[148] India established policies in five of the eight GCII cleantech-friendly policy categories, including setting ambitious renewable energy

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[141] *Id.*

[142] *See, e.g.*, ERNST & YOUNG, RENEWABLE ENERGY COUNTRY ATTRACTIVENESS INDEX (May 2018), https://www.ey.com/Publication/vwLUAssets/ey-recai-51-pp-10-11-index-dps-27-april/$FILE/ey-recai-51-pp-10-11-index-dps-27-april.pdf [https://perma.cc/24LQ-X4AH].

[143] GCIP 2017, *supra* note 93.

[144] *Id.*

[145] BRICS stands for Brazil, Russia, India, China, and South Africa. They are the major emerging economies. *See* GCIP 2017, *supra* note 93, at 25.

[146] *Id.* at 25.

[147] *Id.* at 34.

[148] *See, e.g., Renewable Energy Country Attractiveness Index*, *supra* note 142.

installation target,[149] providing subsidies for renewable energy installations, renewable feed-in tariffs, and renewable energy certificates.[150] Early-stage cleantech finance in India is quite developed, and several cleantech funds and investors are active within the Indian cleantech ecosystem.[151] However, India does not perform well in providing public R&D budget for cleantech or in establishing cleantech organizations and clusters.[152] There has been a significant relative drop in India's public cleantech R&D budget.[153]

Concerning cleantech innovation output, India's low scores in emerging cleantech innovation is predominantly due to a relatively low amount of early-stage venture capital investment. India's low performance in commercialized cleantech likely a result of little late-stage private investment in cleantech, low cleantech exports, and a relative weakness in renewable energy jobs relative to India's total workforce.[154] Of the eight GCIP partnering developing countries, only Morocco and Pakistan score lower than India in the indicator of commercialized cleantech innovation.[155]

b. *Turkey*

Next turning to Turkey, its general innovation capacities are low, and so are its cleantech-specific innovation capacities and output of cleantech innovation.[156] Turkey has a poor-performing innovation system in general because of its political and economic instability, regulatory uncertainty, and disconnection between research institutions and the industry.[157] However, Turkey has a significant amount of early-stage entrepreneurship and high-perceived opportunities for entrepreneurship.[158] Turkish society has yet to fully embrace concepts inherent in entrepreneurship, such as risk-taking and the possibility of failure; the culture prefers stability and the assurance brought by a steady income.[159] While setting up a business in Turkey can be difficult, Turkey does have an extensive network of business organizations and industry clusters.[160]

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149 India set a target of reaching 175GW installed renewable energy capacity by 2022. *See* GCIP 2017, *supra* note 93, at 25.

150 *Id*. at 27.

151 *Id*. at 25.

152 *Id*. at 34.

153 *Id*. at 22.

154 *Id*. at 34.

155 GCIP 2017, *supra* note 93, at 25 (noting that India's levels of renewable energy consumption are in line with some developed countries, such as Australia and Belgium).

156 *Id*

157 *Id*.

158 *Id*.

159 *Id*.

160 *Id*. at 68.

Turkey has a nascent cleantech innovation system, which scores low in cleantech-specific drivers. Turkey offers policies in three out of the eight GCII cleantech-friendly government policies categories.[161] Turkey's government has recently outlined cleantech innovation as one of its focal points in its business strategy; public R&D expenditure represented 1.06% of GDP in 2015, a 17% increase compared to the 2014 budget.[162]

Turkey's evidence of emerging cleantech also received a low score. It has limited environmental patenting activity.[163] Only a few successful Turkish cleantech start-ups have advanced past the early-funding stage. Though Turkey has a relatively high presence of venture capital firms, these firms' investments in cleantech start-ups remain low compared to the overall GDP.[164]

Turkey scores well below the average on commercialized cleantech innovation.[165] This trend is intensified by increased cleantech commodity imports, which most likely come from the increase in renewable energy capacity that Turkey is experiencing. Turkey's very low export figure for cleantech commodities indicates that the country faces difficulties in transforming its innovation inputs into commercialized products.

c. *Morocco*

Morocco scores low in its general innovation capacities, and lacks any significant output of cleantech innovation.[166] This may be explained by Morocco's lack of a streamlined innovation support system. Its general innovation inputs are emerging yet growing.[167] Morocco also performs poorly in the assessment of institutions, policy, educational system, markets, and business sophistication.[168]

In regard to perceived entrepreneurial opportunities, Morocco scores higher than the global average.[169] However, there is a lack of a strong national entrepreneurial culture; entrepreneurship is not highly regarded within Moroccan society, due to its risk-prone nature and risk of failure.[170]

Morocco lags in providing the necessary incentives and support structures for a thriving domestic cleantech innovation pipeline. While the government has dedicated significant funds to renewable energy projects, the country lacks a

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[161] *Id.* at 69 (identifying the following clean tech policies: transport obligation; transportation efficiency or emission standards; renewable energy standard and/or feed-in tariffs; electric utility quota obligation; government tendering/green procurement.).

[162] *Id.*

[163] *Id.*

[164] *Id.* at 67.

[165] *Id.*

[166] *Id.* at 38.

[167] *Id.*

[168] *Id.* at 39.

[169] *Id.* at 38.

[170] *Id.* at 39.

centralized system to support the financing of cleantech start-ups.[171] The government's considerable effort for Morocco to become the North African leader in renewable technology commercialization did not success, as Morocco lags behind the world average in the number of active cleantech-friendly policies and fails to produce effective demand-side pull on domestic cleantech innovation.[172] Morocco's total public spending on cleantech-related R&D is estimated to be very low.[173] Cleantech start-ups struggle to access early-stage investment outside a few cleantech-specific early-stage funds.[174]

Morocco poor performance in innovation capacity is largely due to a lack of significant cleantech innovation outputs, which accounts for 50% of the innovation capacity score in our methodology.[175] With only sixteen cleantech-related patents issued in 2013, Morocco has strained to create successful cleantech research results.[176] Start-ups are mainly early-stage and struggle to gain commercial traction due to limited demand in the domestic market and lack of investor interest to provide means to scale up their products.[177] While Morocco sets renewable energy projects as a focus of policy and public funding, they show little evidence of contributing to domestic cleantech innovation to date. Morocco's cleantech-related imports and exports rank lower than most countries analyzed in the GCII.[178]

3. Observations

Based on the overall assessment and the case studies above, this article identifies the following major areas for improvements for at least the fifteen developing countries studied by GCII 2017 and GCIP 2017.

First, these developing countries all scored lower than average on the general innovation input indicators, meaning that they must upgrade their general capacities for innovation. As shown in Part II.A.1, general capacities for innovation demonstrate a country's strength in institutions, human capital and research ability, infrastructure, and market and business sophistication.

Second, developing countries need to upgrade their input to cleantech sectors. These upgrades can include providing more cleantech-friendly government policies resulted from close consultation and coordination with the private sector. Furthermore, developing countries should connect public sector cleantech R&D activities with the private sector, establish more cleantech-related industry clusters, and strengthen the connection between cleantech innovators and potential investors or industrial partners.

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[171] *Id.* at 38.
[172] *Id.*
[173] *Id.* at 39.
[174] *Id.*
[175] *Id.* at 38.
[176] *Id.* at 39.
[177] *Id.*
[178] *Id.*

The overall assessment also demonstrates that adequate inputs for both the general innovation drivers and the cleantech-specific innovation drivers are necessary for cleantech innovation to thrive. Good input to cleantech-specific innovation drivers alone is not enough. For example, India performed well in its input to cleantech-specific innovation drivers, but does not possess strong cleantech innovation outputs because inadequate general innovation capacities.[179] Moreover, sufficient input to general innovation capacities alone does not automatically translate to sufficient output for cleantech innovation. For example, as shown in Figure 3, Saudi Arabia scores above average for general innovation drivers (in fact, Saudi Arabia scores top for the general innovation inputs part of general innovation drivers).[180] But, as shown in Figure 4, Saudi Arabia lacks almost any cleantech-specific drivers for innovation – it has not focused on cleantech innovation and as a result, as shown in Figure 2, Saudi Arabia has no output for cleantech innovation.[181]

III. PROPOSAL FOR DOMESTIC CLEANTECH INNOVATION BY DEVELOPING COUNTRIES

Based on the discussions in Part I and the observations in Part II, this part of this article explores how developing countries may establish domestic cleantech innovation. As the reality check in Part II.B reveals, at least some developing countries must build up both general and cleantech-specific innovation capacities. This articles suggest a developing country may accomplish this through increased international aid and international cooperation. This article also proposes that a developing country should send clear policy signals on the government's long-term commitment for cleantech innovation and promote diverse innovation tools, such as customized IPR regime, prizes, and innovation commons.

A. *The Different Capacities of Developing Countries*

As shown in Part II.B, the general and cleantech-specific innovation capacities of developing countries vary according to their economic development status. This article classifies developing countries into emerging economies, the LDCs, and the rest of developing countries. Each of these three groups likely has different capacities for domestic cleantech innovation.[182]

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[179] *See* discussion *infra* Section II.B.2.a (citing GCIP 2017, *supra* note 93, at 26).

[180] GCIP 2017, *supra* note 93, at 5.

[181] *Id*.

[182] Peter K. Yu, *Intellectual Property Enforcement and Global Climate Change, in* RESEARCH HANDBOOK ON INTELLECTUAL PROPERTY AND CLIMATE CHANGE 107, 117 (Joshua D. Sarnoff ed., 2016).

1. Emerging Economies

A country is an emerging economy when its economy is progressing toward an advanced economy and the country is progressing toward becoming a developed country.[183] Different international institutions have different conclusions on what countries are emerging economies. However, multiple international institutions have all regarded these countries as emerging economies: Brazil, Chile, China, Colombia, Hungary, Indonesia, India, Malaysia, Mexico, Peru, Philippines, Poland, Russia, South Africa, Thailand, and Turkey.[184]

Emerging economies will be motivated to build domestic cleantech innovation in their active pursuit of economic development coupled with pressure from the global community to reduce GHG emissions.[185] Emerging economies — such as India — may also face domestic demands for cleantech innovation to reduce GHG emissions. The public health impact of GHG emissions also affect economic development and political stabilities.[186] The difficulty of importing foreign cleantech at satisfactory prices may further exacerbate these external and internal pressures, and place pressure emerging economies to invest in domestic cleantech innovation.

Compared to other developing countries, emerging economies are likely more prepared for domestic cleantech innovation.[187] Emerging economies have already achieved benchmark levels of economic development, technology proficiency and resource endowment that make domestic cleantech innovation feasible.[188] These countries may have a large number of scientists and engineers capable of conducting cleantech R&D and adequate financial resources to fund cleantech R&D.[189]Recent empirical studies show that emerging economies have rapidly increased their share of global cleantech patenting.[190] According to one

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[183] Jim Chappelow, *Emerging Market Economy*, INVESTOPEDIA (Oct. 4, 2019), https://www.investopedia.com/terms/e/emergingmarketeconomy.asp [https://perma.cc/A585-QJ3F].

[184] *Id.*

[185] Jerome Reichman et al., *Intellectual Property and Alternatives: Strategies for Green Innovation* 33-36 (Chatham House, Energy, Env't and Dev. Programme Paper No. 08/03 2008), https://scholarship.law.duke.edu/cgi/viewcontent.cgi?article=2915&context=faculty_scholarship [https://perma.cc/W6K7-NLE5].

[186] *Id.* at 35.

[187] *Id.* at 34-36.

[188] Shamnad Basheer & Annalisa Primi, *The WIPO Development Agenda: Factoring in the "Technologically Proficient" Developing Countries, in* IMPLEMENTING WIPO'S DEVELOPMENT AGENDA 100, 101 (Jeremy DeBeer, ed., 2009).

[189] Reichman et al., *supra* note 185, at 33-36.

[190] In 2000-2005, Japan, Germany, and the U.S. – together accounted for 60% of the total technological innovation for climate change mitigation. Meanwhile, the increase in patent filing of certain emerging economies, China and Russia in particular, was impressive; while the quality or value of the inventions, their performance was much less so, "of relatively minor

study, patent filings from China, although still comprising a small percentage of overall patent filings in the cleantech industry, have more than quadrupled.[191] This is likely due to a combination of factors, including China's push to compete in the solar energy market, its focus on cleantech as a way to combat soaring air pollution, and its recent focus on protecting innovation through patenting.

2. Least Developed Countries

The UN designates which countries are LDCs. The UN bestows the LDC designation by evaluating a country's gross national income per capita, human capital in terms of health and education, and economic vulnerability.[192] Countries can enter or graduate from the UN LDC designations if they meet the UN-defined inclusion or graduation thresholds.[193] As of June 2020, UN has designated 47 LDCs.[194]

Harmful impacts of climate change disproportionately affect LDCs.[195] These negative effects can range from rising sea-levels and saltation, decreased crop yields and food production, direct and indirect health consequences, extreme weather events, and exacerbated migration push factors.[196]

Meanwhile, LDCs are likely the least equipped to counter climate change. For these countries, resource constraints and a lack of domestic capacity for importing foreign cleantech or producing domestic cleantech prevent them from

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economic value." *See* Antoine Dechezleprêtre et al., *Invention and Transfer of Climate Change-Mitigation Technologies: A Global Analysis*, 5 REV. OF ENVTL. ECON. & POL'Y 109, 115-17 (2011), http://reep.oxfordjournals.org/content/5/1/109.full.pdf+html [https://perma.cc/EQZ9-669C]. A more recent study (2017) noticed that inventors residing in OECD countries make up 94% of all EST patents filed under the PCT during 1999-2011. The six leading countries – the U.S., Japan, Germany, France, UK and Korea— account for 78% of world total of EST patents. Those of non-OECD countries takes up 6%, where Brazil, India, China and Russia account for 3.6%, and China along accounts for 2%. WEI ZHUANG, INTELLECTUAL PROPERTY RIGHTS AND CLIMATE CHANGE 39 (Cambridge Univ. Press, 2017).

[191] KILPATRICK TOWNSEND, INDUSTRY-FOCUSED PATENTING TRENDS 42 (2019), https://apps.kilpatricktownsend.com/files/Patent%20Trends%20Study.pdf [https://perma.cc/A9WS-F7ZV].

[192] *LDC Identification Criteria & Indicators*, UNITED NATIONS, https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-criteria.html (last visited Apr. 12, 2019) [https://perma.cc/VR8Y-PTK8].

[193] *Id.*

[194] Comm. for Dev. Policy, *List of LDCs*, UNITED NATIONS (2018), https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/ldc_list.pdf [https://perma.cc/S79H-WU8W].

[195] *The Climate Justice Declaration*, ENVTL. JUSTICE INITIATIVE (2004), http://www.umich.edu/~snre492/cgi-data/ejcc_principles.html [https://perma.cc/3RVZ-FE6S].

[196] *Id.*

responding to climate change adequately.[197] LDCs may not have technology bases at all, and must continue depending on the acquisition and adaptation of foreign cleantech. Thus, building up technological capacities is a priority for LDCs, whether for immediate cleantech importation or eventual necessary domestic cleantech innovation.

3. The Remaining Developing Countries

The remaining developing countries are countries who are in the middle-income group,[198] but are not typically regarded as emerging economies. They are less wealthy and slower in economic development than emerging economies, but perform better than LDCs. Such countries include, for example, Algeria, Romania, and Zambia.[199]

These countries may have resources for attracting foreign investments, and also some capacity for adapting and implementing foreign cleantech or for creating their own cleantech innovation. However, they have not yet arrived at fully independent cleantech innovation.

In sum, developing countries display a varied ability to attract, adapt, and implement foreign cleantech, and to generate their own cleantech innovation. Emerging economies have shown their capacity to attract foreign technologies and to increasingly produce their own cleantech innovation. LDCs contribute to climate change the least and are most vulnerable to the negative impacts of climate change, but are the least equipped capacity-wise for foreign cleantech importation and domestic cleantech innovation. Meanwhile, as discussed in Part I.A, to effectively address climate change and build sustainable development, all countries ideally should have the capability for domestic cleantech innovation. This article will propose a pathway for enabling developing countries for domestic cleantech innovation.

B. *Proposal: International Aid, International Cooperation, Domestic Innovation*

This article proposes that a developing country should progress toward independent domestic cleantech innovation in several stages. The first step is to leverage international aid to build up essential capacities for domestic cleantech innovation and cleantech importation. Most LDCs probably would start at this point. The next step is to seek international cooperation to learn advanced cleantech innovation practices through mutually beneficial cooperation. This occurs when a developing country has essential general innovation capacities.

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[197] Peter K. Yu, *The International Enclosure Movement*, 82 IND. L. J. 827, 851-52, https://www.repository.law.indiana.edu/cgi/viewcontent.cgi?article=1373&context=ilj [https://perma.cc/DC4H-Y44P].

[198] *World Bank Country and Lending Groups*, World Bank (Oct. 19, 2019), https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups [https://perma.cc/63KH-EWK9].

[199] *Id*.

The final step is independent domestic cleantech innovation, and some emerging economies are already at this stage at least in specific technology sectors.

1. International Aid to Build Capacities for Cleantech Innovation

Most developing countries – especially LDCs –need assistance to combat climate change. In particular, as discussed in Part III.A, LDCs are most vulnerable to climate change despite contributing the least to it, due to their low level of economic development activities. Because of limited resources, market size and technological capability in LDCs, foreign cleantech owners may not transfer their technologies to LDCs even if LDCs ramp up their IPR protections. Therefore, LDCs in particular require international aid in order to attract foreign cleantech and develop domestic cleantech innovation.

Developing countries have requested support to address climate change via financial aid, technology transfer, and capacity building.[200] As discussed in Part I.B, international cleantech transfer has been limited, which can be partially explained by the lack of local capacity or resources required to import, adapt or implement foreign cleantech in developing countries, especially LDCs. While it is critical that LDCs import cleantech suited to their particular conditions and circumstances, it is equally as important for LDCs to strengthen domestic capacity to absorb such technologies and to eventually create their own cleantech down the road.[201] This article discusses how to provide international aid in the forms of financial assistance and capacity building.

From 2011-2020, the global community committed to providing at least 0.15–0.20% of their annual national income in international aid to the LDCs, mainly to improve the LDCs' production capacity.[202] In reality, as 2017, financial aid levels to the LDCs fall short of this target by $33 billion to $50 billion per year.[203]

On the cleantech front, to help developing countries, the UNFCCC mandated international aid to developing countries. "*Support, including financial support, shall be provided to developing country Parties* [emphasis added] for . . . strengthening cooperative action on technology development and transfer at

[200] *See Summary of Climate Summit 2014,* INT'L INST. FOR SUSTAINABLE DEV. (Sept. 23, 2014), http://www.iisd.ca/climate/cs/2014/html/crsvol172num18e.html [https://perma.cc/AP9W-Z4RL] (statements by leaders from India, Equatorial Guinea, Malaw, Guinea-Bissau, Fiji, Lesotho, Mauritania, Namibia, Sweden, Tanzania).

[201] Press Release, UNCTAD, LDC - Progress in Least Developed Countries Hinges on Access to Modern Energy, New United Nations Report Says (Nov. 22, 2017), https://unctad.org/en/pages/PressRelease.aspx?OriginalVersionID=436 [https://perma.cc/74NJ-6DG5].

[202] UN-OHRLLS, *Istanbul Declaration and Programme of Action*, UNITED NATIONS (Oct. 26, 2019) http://unohrlls.org/about-ldcs/istanbul-programme-of-action/ [https://perma.cc/52A6-2RNS] (the actors here include donor countries, developing countries, parliaments, the private sector, civil society, the UN system and international and regional financial institutions); Press Release, UNCTAD, *supra* note 201.

[203] Press Release, UNCTAD, *supra* note 201.

different stages of the technology cycle, with a view to achieving a balance between support for mitigation and adaptation."[204] The UNFCCC established financial mechanisms to bolster fiscal assistance, and the Global Environment Facility (GEF) and the Green Climate Fund (GCF) are currently the UNFCCC's two operational entities. The GEF, established in 1992, administers several funds for the UNFCCC, such as the Least Developed Countries Fund and the Special Climate Change Fund, and the Adaptation Fund.[205] The GCF, established in 2010, operationalizes the commitment of UNFCCC developed country parties' to mobilize $100 billion annually to address developing countries' needs in climate actions.[206] This annual commitment extends to 2020,[207] and developed countries have pledged to extend this financial assistance to the year 2025.[208] Thus far, both developed countries and emerging economies have contributed to the GCF.[209] As of January 2019, the GCF raised $10.3 billion equivalent in pledges from forty-eight international donors, which the GCF utilized to fund climate action projects in developing countries.[210]

While financial support is key, other forms of international aid are as imperative, if not more, so in helping the LDCs build their domestic capacities for cleantech innovation and importation. Such assistance includes building hardware and technological infrastructure, such as highways and communication networks, constructing software infrastructure, and enhancing R&D capability, enrollment in higher education, stable policy, and regulatory

[204] UNFCCC, *supra* note 3, art. 10.6

[205] GLOB. ENVTL. FACILITY, https://www.thegef.org/ (Dec. 10, 2018) [https://perma.cc/H2KF-TYD4].

[206] *See* Conference of the Parties, *Action Taken by the Conference of the Parties at its Fifteenth Session*, ¶ 8, U.N. Doc. FCCC/CP/2009/11/Add.1 (Mar. 30, 2010). Subsequently, developed countries parties expressed the intent to continue such collective financial mobilization goal through 2025. *See* Conference of the Parties, *Action Taken by the Conference of the Parties at its Twenty-first Session*, ¶ 53, U.N. Doc. FCCC/CP/2015/10/Add.1 (Jan. 29, 2016).

[207] U.N. Framework Convention on Climate Change, Conference of the Parties, Actions Taken by the Conference of the Parties at Its Fifteenth Session, ¶ 8, U.N. Doc. FCCC/CP/2009/11/Add.1 (Mar. 30, 2013).

[208] U.N. Framework Convention on Climate Change, Historic Paris Agreement on Climate Change: 195 Nations Set Path to Keep Temperature Rise Well Below 2 Degrees Celsius (Dec. 13, 2015), http://newsroom.unfccc.int/unfccc-newsroom/finale-cop21 [https://perma.cc/6VYB-FTUT].

[209] *A Summary Report of the UN Climate Summit 2014*, INT'L INST. OF SUSTAINABLE DEV. (Sept. 23, 2014), http://www.iisd.ca/climate/cs/2014/html/crsvol172num18e.html [https://perma.cc/K34H-L7NS].

[210] *Resource Mobilization*, GREEN CLIMATE FUND (Oct. 16, 2019), https://www.greenclimate.fund/how-we-work/resource-mobilization [https://perma.cc/2LKE-LTLC].

environments.[211] Deficiency in any of these areas affects an LDC's advancement in cleantech innovation. This is evident with R&D investment, which enhances a country's technological innovation. For most LDCs, the ratio of expenditure on R&D to gross domestic product remains low, at less than 1%, while the global average is above 2.3%.[212] In 2013, only seven scientific and technical journal articles were published for every 1 million people in African LDCs, compared to about 1,100 scientific and technical journal articles published for every 1 million people in developed countries.[213] Another form of aid LDCs must acquire, human capital – e.g., science and technology literate citizens — is necessary to produce useful R&D results or to adapt and implement foreign cleantech.[214] In 2013, LDCs' gross enrollment ratio in tertiary education was less than 9%, compared with 33% worldwide.[215] In 2015, about 40% of all out-of-school children and adolescents in the world lived in the LDCs.[216]

The global community has focused on international aid to help capacity-building in developing countries. The 2015 Paris Agreement formally recognized capacity-building as a key UNFCCC effort.[217] As a result, the UNFCCC established a Paris Committee on Capacity Building.[218] Besides the UNFCCC financial mechanisms, such as the GEF and the GCF, the UNFCCC has also set up technology support for developing countries. For instance, the UNFCCC established the Technology Mechanism program, which provides technical assistance (including capacity building) for cleantech development and deployment upon receiving a developing country's request.[219] Meanwhile, the UN Agenda 2030 established a target for capacity building in one of the seventeen goals; SDG 17 includes a specific sub-goal to "enhance international support for implementing effective and targeted capacity-building in developing

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[211] U.N. Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States, Closing the Technology Gap in Least Developed Countries (Jan. 7, 2019), http://unohrlls.org/news/closing-technology-gap-least-developed-countries/ [https://perma.cc/V8EH-WTUH] [hereinafter *Closing the Technology Gap*].

[212] World Bank, *Research and Development Expenditure (% of GDP)*, (Apr. 20, 2019), https://data.worldbank.org/indicator/gb.xpd.rsdv.gd.zs [https://perma.cc/B5DT-HFAP]; *Closing the Technology Gap*, *supra* note 211.

[213] *Closing the Technology Gap*, *supra* note 211.

[214] *Id.*

[215] *Id.*

[216] *Id.*

[217] Paris Agreement, *supra* note 2, art. 11.

[218] U.N. Framework Convention on Climate Change, Paris Committee on Capacity-building (PCCB) (Oct. 16, 2019), https://unfccc.int/process-and-meetings/bodies/constituted-bodies/paris-committee-on-capacity-building [https://perma.cc/TV3V-B6EX].

[219] U.N. Framework Convention on Climate Change, Technology Mechanism (Oct. 16, 2019), http://unfccc.int/ttclear/support/technology-mechanism.html [https://perma.cc/C3EG-9A3Z].

countries."[220] As a result, in 2017, the Technology Bank for the LDCs came into operation to build up the LDCs' scientific research and innovation capacities.[221] The purpose of the Technology Bank for the LDCs is to implement projects and activities in the LDCs and to serve as a knowledge hub connecting LDCs' science, technology and innovation demands with available resources and actors who can respond to these needs.[222]

2. International Cooperation for Cleantech Development and Importation

Unlike international aid, which is a voluntary transfer of resources from a country or a multinational institution to assist another country, international cooperation needs to be mutually beneficial. Mutually beneficial means that the parties cooperate on mutually agreeable terms that address the parties' major interests.

When a developing country develops essential capacities for domestic cleantech innovation, or for attracting, adapting, and implementing foreign cleantech, it can attract international cleantech cooperation, e.g., with entities in developed countries. With international cleantech cooperation, a developing country can learn about advanced practices and how to obtain revenue, which in turn helps develop capacities for domestic cleantech innovation and attract foreign cleantech.

The UN, the UNFCCC and the TRIPS Agreement all demand international cooperation for technology development and deployment.[223] The UN's Agenda 2030 calls for the global community to fulfill seventeen sustainable development goals by 2030.[224] Of the seventeen sustainable development goals, SDG 17 recognizes global partnership is a necessity for realizing the remaining sixteen goals.[225] While emphasizing the transfer of cleantech from developed countries to developing countries, the UNFCCC also requires all participating parties to "*promote and cooperate* [emphasis added] in the development, application, and diffusion, including transfer, of technologies" relevant to GHG emissions.[226]The 2015 Paris agreement requires its members to cooperate on cleantech development and transfer: "Parties, noting the importance of technology for the

[220] U.N. Sustainable Development Goals, *Transforming our World: the 2030 Agenda for Sustainable Development,* (Oct. 16, 2019), https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals [https://perma.cc/PNS7-EJZT] [hereinafter *Transforming our World*].

[221] Technology Bank for the Least Developed Countries, *Who We Are* (Oct. 16, 2019), https://www.un.org/technologybank/content/who-we-are [https://perma.cc/YNV6-6FKQ].

[222] U.N. Technology Bank for the Least Developed Countries, *What We* Do (Oct. 16, 2019), https://www.un.org/technologybank/content/current-activities [https://perma.cc/J4WK-647Y]

[223] Transforming our World, *supra* note 220.

[224] *Id.*

[225] *Id.*

[226] UNFCCC, *supra* note 3, art. 4.1.

implementation of mitigation and adaptation actions under this Agreement and recognizing existing technology deployment and dissemination efforts, *shall strengthen cooperative action* [emphasis added] on technology development and transfer."[227]

Meanwhile, the TRIPS Agreement mandates technical cooperation between developed countries and developing countries, on terms and conditions that are mutually agreed upon, though in favor of developing countries.[228] "In order to facilitate the implementation of this Agreement, developed country Members shall provide, on request and on *mutually agreed terms and conditions* [emphasis added], technical and financial *cooperation in favor of* [emphasis added] developing and least-developed country members."[229]

In reality, international cooperation in cleantech development and deployment has occurred at multiple levels: multilateral, regional, bilateral, and subnational. First turning to multinational cooperation, Exemplary multilateral efforts for fostering international cleantech cooperation include the aforementioned UNFCCC Technology Mechanism (TM) and the UN Agenda 2030 Technology Facilitation Mechanism (TFM). Among various policy guidance and project implementation functions, the NFCCC TM fosters collaboration among climate technology stakeholders.[230] When a developing country identifies its needs for cleantech development, the UNFCCC TM then locates an organization in a developed country that is interested in working with the developing country to co-develop clean technology needed, or adapt and deploy already available clean technology. By September 2017, the UNFCCC TM had more than 377 organizations in its worldwide network that respond to the requests of developing countries; 82 developing countries submitted 190 cleantech assistance requests to the UNFCCC TM, and responses to 24 of these requests had been successfully implemented.[231] The UN TFM, established to fulfill the Sustainable Development Goals, facilitates multi-stakeholder collaboration and partnerships through sharing information, experiences, best practices, and policy advice among stakeholders in global sustainable development.[232]

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[227] Paris Agreement, *supra* note 2, art. 10.2

[228] TRIPS Agreement, *supra* note 54, art. 67

[229] *Id.* art. 67 ("Such cooperation shall include assistance in the preparation of laws and regulations on the protection and enforcement of intellectual property rights as well as on the prevention of their abuse, and shall include support regarding the establishment or reinforcement of domestic offices and agencies relevant to these matters, including the training of personnel.").

[230] Tech. Exec. Comm., *Evaluation of the Poznan Strategic Programme on Technology Transfer*, U.N. Doc. FCCC/SBI/2015/16, at 28 (2015).

[231] *2017 Joint Annual Report* , *supra* note 4, at 14-16.

[232] United Nations, Sustainable Development Goals, *Technology Facilitation Mechanism* (Dec. 12, 2018), https://sustainabledevelopment.un.org/tfm [https://perma.cc/9V2X-P3XK].

Next turning to regional cleantech cooperation, exemplary efforts include Mission Innovation (MI) and Breakthrough Energy Coalition (BEC). MI started in 2015 among the governments of twenty-four countries and the European Union,[233] and aims to provide affordable and reliable clean energy solutions by drastically accelerating clean energy innovation so to achieve performance breakthroughs and cost reductions.[234] One of MI's near-term goals is to double government spending on clean energy R&D over five years (2015-2020).[235] The BEC is a coalition of more than two dozen wealthy investors;[236] it pools investments in early-stage clean energy technology companies to accelerate the commercialization and deployment of clean energy technologies. This investment group aims to bring advanced government-funded research — e.g., coming out of the MI countries — to market earlier through patient and risk-tolerant investment.[237]

Thus far, most bilateral cleantech cooperation relationships are between a developed entity (e.g., from Canada, the EU, or the U.S.) and an emerging economy (e.g., China or India). This type of bilateral cooperation is important, as emerging economies are major GHG emitters and require cleantech for sustainable economic development. Such partnerships can be a "win-win solution," especially given the reality that developed countries likely have advanced research practices and emerging economies have rapidly increased their R&D expenditures.[238] China demonstrates the success of bilateral cooperation, and is expected to become the global leader in clean energy R&D, exceeding that of the U.S., EU, or Japan.[239]

Meanwhile, turning to other types of bilateral cooperation, there is a recent trend of South-to-South cleantech cooperation.[240] China, an emerging economy, has cooperated with countries in Africa – such as Zambia and Ghana – on

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[233] *Member Participation*, MISSION INNOVATION (Oct. 16, 2019), http://mission-innovation.net/countries/ [https://perma.cc/ZL3S-JUV2].

[234] *The Goal*, MISSION INNOVATION (Oct. 16, 2019), http://mission-innovation.net/the-goal/ [https://perma.cc/KKM9-B6AU].

[235] *Id.*

[236] *Who We Are*, BREAKTHROUGH ENERGY (Oct. 16, 2019), http://www.b-t.energy/coalition/who-we-are/ [https://perma.cc/X22R-4TJP].

[237] *Breakthrough Energy Ventures*, BREAKTHROUGH ENERGY (Oct. 16, 2019), http://www.b-t.energy/ventures/ [https://perma.cc/9W8N-GFNC].

[238] Daniele Poponi, *Energy Technology Perspectives 2015: The Role of Emerging Economies*, INT'L ENERGY AGENCY (Sept. 11, 2015), https://www.iea.org/media/etp/etp2015/ETP2015Webinar11Sept.pdf [https://perma.cc/K2V7-5QP7].

[239] *Id.*

[240] Tech. Exec. Comm., *Potential of South-to-South and Triangular Cooperation on Climate Technologies for Advancing Implementation of Nationally Determined Contributions and National Adaptation Plans*, UNFCCC (2018), http://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/brief9/7a74a2f17f204b6ba17f1ec965da70d7/f4e361cd56d4463a8daa4ab29a1254db.pdf [https://perma.cc/E7E3-AWX4].

various renewable energy projects, spanning wind, solar panel, and hydropower technologies.[241] South-to-South cleantech cooperation is a development in international cleantech cooperation that is worthy of further exploration. Some South-to-South cooperation reaches beyond bilateral and is triangular; that is, involving the participation of a developed country or an international agency such as the United Nations Development Program.[242] Triangular cooperation is a promising international cooperation model for assisting a developing country's economic development because a developing country may have their development needs better understood by an emerging economy, but they also receive added input from a developed country or an international agency.

3. Domestic Cleantech Innovation

Through international aid and international cleantech cooperation, a developing country such as an LDC may eventually march into domestic cleantech innovation. For domestic cleantech innovation, developing countries should develop cleantech innovation systems according to their local circumstances. National systems of innovation are complex and multifaceted. There is no "one size fits all" approach. Different innovation approaches are necessary to address different situations.

With that said, this article proposes that a developing country acts to stimulate cleantech innovation in its private sector. Specifically, a developing country should send clear policy signals to its private sector about the government's long-term commitments to climate actions and sustainable development. A developing country should also employ diverse innovation tools for stimulating cleantech innovation, such as customized IPR laws and non-IPR means such as prizes and innovation commons.

a. *Clear Cleantech Policy Signals to the Private Sector*

Cleantech innovation needs the active participation of both the public sector and the private sector. Public sector entities such as public research institutions tend to focus on long-term basic research,[243] while private sector entities such as commercial companies tend to focus on short-term applied research.[244] Both long-term basic research and short-term applied research are necessary for cleantech innovation. Often, research results from the former become funding ideas for new companies and industries in the private sector.

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[241] *Id.*

[242] *Id.*

[243] Research that aims at expanding the existing base of scientific knowledge. *See Difference Between Basic and Applied Research*, KEY DIFFERENCES (Oct. 16, 2019), https://keydifferences.com/difference-between-basic-and-applied-research.html [https://perma.cc/VX5M-BDNU].

[244] *Id.*

The private sector likely plays a substantial role in cleantech innovation because it tends to invest the most in cleantech R&D.[245] As indicated in Part II.A, one useful indicator of innovation activities is the amount of R&D spending. The private sector funds over 60% of cleantech R&D and almost 70% of overall R&D globally.[246] A 2017 compilation of R&D spending in the G20 countries shows that on average, 1.26% of GDP is spent on R&D by the private sector, compared to 0.65% of by governments, and 0.13% by other actors such as philanthropic foundations.[247] Governments can increase cleantech activity by the private sector by establishing clear priorities and policy signals for cleantech innovation, which has been recommended by UNFCCC Technology Executive Committee to the UNFCCC member countries.[248] To accelerate private sector cleantech innovation, governments should also prioritize research resources (e.g., human, institutional and financial) for cleantech innovation efforts, because it will affect the investment behavior in society.[249] Empirical data shows that when a government prioritizes research for long-term university research, the private sector often responds with short-term application research.[250]

In regards to patents, empirical studies show a positive correlation between levels of patenting activity and the stringency of environmental regulations.[251] As shown in Part II.A, patenting activities is one measure for the output of cleantech innovation. A global survey on clean energy technology ("CET") patenting activities reveals that following the 1997 adoption of the Kyoto Protocol,[252] CET patenting increased 20 percent per year, much higher than patenting growth for other traditional energy sources such as fossil fuel and nuclear energy.[253] Government policies must properly motivate the private sector

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245 Reichman et al., *supra* note 185, at 6.

246 *Id.*

247 *Global Private and Public R&D Funding*, SCIENCEGRAM UK (Oct. 16, 2019), https://scienceogram.org/blog/2013/05/science-technology-business-government-g20/ [https://perma.cc/7GLR-N5N3].

248 *2017 Joint Annual Report*, *supra* note 4, at 12.

249 *Id.* at 11.

250 Larry Smarr, *Back to the Future: The Increasing Importance of the States in Setting the Research Agenda,* in DEFINING VALUES FOR RESEARCH AND TECHNOLOGY – THE UNIVERSITY'S CHANGING ROLE 56 (Greenough et al. ed, 2007).

251 Frans P. de Vries & Cees Withagen, *Innovation and Environmental Stringency: The Case of Sulfur Dioxide Abatement* 28 (Dept. of Econ. & CentER, Tilburg Univ. and Dept. of Econ., Free Univ. Amsterdam, Discussion Paper Series No. 2005-18, 2005).

252 The Kyoto Protocol is an international agreement under the UNFCCC. It commits its parties to set internationally binding emission reduction targets. *See* UNFCCC, *What is the Kyoto Protocol?* (last visited Oct. 25, 2019), https://unfccc.int/kyoto_protocol [https://perma.cc/VW8S-K7TU].

253 *See* Petro Roffe, *Patents and Clean Energy, Bridging the Gap between Evidence and Policy*, WORLD INTELLECTUAL PROPERTY OFFICE 26-27 (July 11, 2011), https://www.wipo.int/edocs/mdocs/mdocs/en/wipo_inn_ge_11/wipo_inn_ge_11_ref_t9.pdf [https://perma.cc/52GX-RYCV].

to invest in cleantech innovation, because public investment in cleantech R&D will be of little worth if the private sector does not convert the results from public investments in cleantech R&D, translate them into industrial applications, and deploy them widely.[254]

To incentivize the private sector's investments in cleantech innovation, governments can establish a price for GHG emission. There appears to be scholarly consensus that a high price for GHG emission directly creates a significant demand-driven and profit-based incentive for the private sector, which in turn will be motivated to provide low-emission products to the market and further invest in cleantech innovation.[255] A price on GHG emission can be established through cap-and-trade policies or GHG emission taxes.[256]

Other government policies to motivate private sector toward cleantech innovation include removing subsidies for incumbent technologies – e.g., subsidies for fossil fuel—and encouraging the demonstration of new cleantech technologies.[257] Governments may also reduce the risks that private investments may incur, such as a lack of adequate IPR protection, lack of a clear legal framework for emissions control and access to infrastructure, political instability and transiency of government commitments.[258]

To alleviate these private sector's concerns, government policies on cleantech innovation need to be sustainable over the long term. This way, the private sector can be certain that its investment in cleantech R&D will have sufficient market demand down the road. Evidence shows that commercializing an innovative cleantech idea into a profitable commercial product takes time. It takes between nineteen and thirty years for top-cited low-carbon technologies to reach the mass-market adoption phase.[259] One suggested approach for bolster the private sector's confidence in long-term demand for cleantech is to spell out stringent GHG emission targets for decades in advance. This can be established through, e.g., domestic government policies or international environmental agreements, and would provide stable financial incentives for a wide array of cleantech solutions.[260]

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[254] Reichman et al., *supra* note 185, at 7.

[255] Keith E. Maskus & Ruth L. Okediji, *Intellectual Property Rights & International Technology Transfer to Address Climate Change: Risks, Opportunities, & Policy Options* 22 (ICTSD, Issue Paper No. 32, 2010), https://www.ictsd.org/themes/climate-and-energy/research/intellectual-property-rights-and-international-technology [https://perma.cc/C383-GRWS]; *see also* Reichman et al., *supra* note 185, at 6.

[256] Reichman et al., *supra* note 185, at 6.

[257] Bateson, *supra* note 79, at 11.

[258] *Id*. at 12, 15-17.

[259] Chatham House, *Who Owns Our Low Carbon Future: Intellectual Property & Energy Technologies* vii (Sept. 2009).

[260] Reichman et al., *supra* note 185, at 6.

b. *Diverse Innovation Tools for Stimulating Cleantech Innovation*

To promote cleantech innovation, the article further suggests that a developing country utilize diverse innovation tools. The article groups diverse innovation tools into two groups: IPR and non-IPR.

i. IPR

The term "intellectual property" refers broadly to creations of the human mind. Intellectual property rights ("IPR") protect the interests of the creators by providing property rights over their creations.[261] The major forms of IPR include patents, trade secrets, copyrights, and trademarks. Patents generally protect innovative technical improvements; trade secrets protect confidential information such as innovative business or technical knowledge that likely contains competitive advantages; trademarks protect the distinctive symbols identifying the source of a product or service; and copyrights protect the artistic expressions of ideas.[262] In the discussion of the development and deployment of technology, patent rights and trade secrets are the most relevant forms of IPR.

A fundamental concept about IPR is that it is territorial in nature.[263] This means an IPR is effective and enforceable only within the territory where the government issuing the IPR has jurisdiction.[264] If a cleantech owner applies for patent protection in a developing country, the patent right granted by that government is only effective in that country, and no one can use the patented cleantech there absent the cleantech owner's permission. However, anyone is free to use that cleantech within the developing country if the cleantech owner does not apply for, or fails to obtain, patent protection in the developing country, or if the patent right over the cleantech is expired or exhausted.[265]

One ongoing dilemma concerning IPR is how to balance its social benefit with its social cost. The social benefit of IPR is that it incentivizes investments in innovation by granting inventors a limited monopoly over their intellectual

[261] World Intellectual Property Organization [WIPO], *What is Intellectual Property?* (last visited October 26, 2019), http://www.wipo.int/about-ip/en/ [https://perma.cc/A4JE-2X7D].

[262] *Id.*

[263] Peng et al., *An institution-based view of global IPR history*, 48 J. INT'L BUS. STUD. 896, 897 (2017).

[264] *Id.*

[265] The IP right over a technology is exhausted over a product or service containing the IP-protected technology upon an authorized sale of the product or service. The TRIPS Agreement does not address the IP exhaustion issue. *See* TRIPS Agreement, *supra* note 54, art. 6. Hence each WTO member may decide, e.g., whether the exhaustion of the IP right over the product or service occurs only within the domestic jurisdiction, or whether authorized sale of the IP-protected product or service abroad also exhausts the IP rights in the domestic jurisdiction. The latter approach has great implication for developing countries' access to IP-protected foreign cleantech.

work.[266] However, IPR's monopoly, albeit limited in time, limits public access to the protected intellectual work.[267] This is the social cost of IPR – the lack of public access to the intellectual work during the effective term of the IPR without the IPR owner's permission, or if it is, it is conditioned on a benefit to the IPR owner, such as payment.[268]

Because of the incentive-benefit and access-cost dichotomy of IPR, countries have tended to adjust IPR laws according to the domestic economic development needs – e.g., to grow domestic industries and to attract foreign investment or technology.

Developed countries such as Switzerland, Denmark, the Netherlands, the U.S., and Japan strengthened their IPR regimes over time, not overnight.[269] Denmark, ranking number one in overall cleantech innovation performance in the GCII 2017 discussed in Part II.A, had no patent law, and was therefore able to liberally copy foreign technology, until 1874. It then provided limited patent protection for up to five years in 1874 (while patents in other countries lasted for a minimum of 12 years), and enacted an official patent law only in 1894.[270] Switzerland adopted it first patent laws in 1888, which was ; a rudimentary patent system, and established a full-fledged system only in 1907.[271] The Netherlands rescinded patent laws between 1869 and 1912 in an attempt to encourage technology imitations.[272] Before 1891, U.S. IPR laws protected U.S.-based authors and inventors and allowed U.S. citizens to legally violate the IPR of foreigners.[273] The U.S. passed the International Copyright Act, which extended IPR protection to foreign works, in 1891.[274] Japan had a weak patent system after the Meiji restoration period of the late 19th century.[275] At that time,

[266] Margaret Kyle & Yi Quan, *Intellectual Property Rights & Access to Innovation: Evidence from TRIPS* 1-2 (Nat'l Bureau of Econ. Res., Working Paper No. 20799, 2014), http://www.nber.org/papers/w20799 [https://perma.cc/UQT2-KW2H].

[267] *Id.*

[268] *Id.*

[269] Peng, *supra* note 263, at 898.

[270] Petra Moser, *Patents and innovation: Evidence from economic history*, 27(1) J.ECON. 23, 26 (2013).

[271] *See* Paticio Saiz & David Pretel, *Why did multinationals patent in Spain? Some historical inquiries*, In ORGANIZING GLOBAL TECHNOLOGY FLOWS 39–59 (Pierre-Yves Donze & Shigehiro Nishimura ed. 2014).

[272] Moser, *supra* note 270, at 26.

[273] B. Zorina Khan & Kenneth L. Sokoloff, *The early development of intellectual property institutions in the United States*, 15 J.ECON. PERSP. 233, 234 (2011); Steve Lohr, *The intellectual property debate takes a page from 19th-century America*, N.Y. TIMES (Oct. 14, 2002); Kaul Raustiala & Christopher Sprigman, *Fake it till you make it: The good news about China's knockoff economy*, 92(4) FOREIGN AFF. 25, 30 (2013).

[274] International Copyright Act of 1891, ch. 565, 26 Stat. 1106 (1891).

[275] Lee G. Branstetter, *Intellectual Property Rights, Innovation & Development: Is Asia Different?*, 8(I) MILLIANIEL ASIA 5, 12-13 (2017).

Japanese patent practice did not adopt the doctrine of equivalents,[276] which meant there was a narrow claim scope for patentees and room for legal imitation. It also provided low patent infringement awards—so low that well-capitalized firms were generally undeterred from making minor alterations to the patented technologies of their rivals.[277] Only when the U.S. started moving manufacturing to low-cost locations, especially to Asia, did Japan begin to strengthen IP protection, so as to attract foreign investments.[278] This illustration of IPR development histories demonstrates IPR protections are strengthened over an extensive period of time.[279] It took the Netherlands 200 years, the U.S. 104 years, and several decades for Japan and Germany.[280] Nonetheless, the progression toward stronger IPR protection over time is clear.

Strong IPR protection facilitates the development of developing countries by attracting foreign direct investments ("FDI").[281] Multiple studies show a positive correlation between perceived strength of IPR protection in developing countries and the volume and quality of FDI they attract.[282] "From the perspective of the investor, countries with strong IPR policies present valuable investment opportunities as strong IPR protection assures that their technology will not be leaked to competitors."[283] Strong IPR protection may also facilitate formal technology transfer such as technology licensing. Technology licensing occurs where an owner of a proprietary technology consents to another party's use of the technology in exchange for value.[284] Strong IPR protection may attract inbound technology licensing only when developing countries have the capacity to absorb and to use foreign technology.[285] In this scenario, technology owners

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[276] Doctrine of equivalents is a tool for a patentee to expand its patent coverage to a feature in the alleged infringing product or service that is equivalent to the feature claimed in the patent. The purpose of this doctrine is to prevent patent infringers from changing the patented product or service in minor or trivial ways without incurring liability. *Id.* at 13.

[277] *Id.*

[278] *Id.* at 15.

[279] Peng, *supra* note 263, at 900.

[280] *Id.*

[281] Samuel Adams, *Intellectual Property Rights, Investment Climate, & FDI in Developing Countries*, 3(3) INT'L BUS. RES. 1, 1 (2010).

[282] *See*, e.g., Branstetter, *supra* note 275, at 9; Edwin Mansfield, *Intellectual Property Protection, Direct Investment, & Technology Transfer* 19 (Int'l Fin. Corp., Discussion Paper No. 19, 1994); Jeong-Yeon Lee & Edwin Mansfield, *Intellectual Property Protection & U.S. Foreign Direct Investment*, 78(2) REV. ECON. STAT. 181, 185 (1996).

[283] Adams, *supra* note 281, at 2.

[284] World Intellectual Property Organization [WIPO], *Successful Technology Licensing*, at 5, WIPO Publication No. 903E (2015), http://www.wipo.int/edocs/pubdocs/en/licensing/903/wipo_pub_903.pdf (last visited July 12, 2015) [https://perma.cc/UZ7Z-LH3L].

[285] Lee G. Branstetter, Raymond Fisman & C. Fritz Foley, *Do Stronger Intellectual Property Rights Increase International Technology Transfer? Empirical Evidence from U.S. Firm-Level Panel Dat*a, 121(1) Q.J.ECON. 321, 322-323 (2006).

in developed countries are more likely to license their technologies to these developing countries due to their low labor and production cost.[286]

On the other hand, strong IPR protection may not facilitate the informal transfer of technology and information to developing countries, such as the LDCs.[287] In the global trade system, a country can advance technology development via a process of duplicative imitation, creative imitation, and then independent innovation.[288] Many developing countries are at the duplicative imitation stage, hoping to absorb foreign technologies into labor-intensive export production and evolve into higher value-added stages such as creative imitation or independent innovation over time. In particular, the LDCs have barely begun this stage of technology development.[289]

The design of IPR laws should vary according to a country's economic development. Hence, the article proposes that a developing country design its IPR laws according to the country's priorities in its current economic development. Specifically, the article suggests a developing country should consider three factors when designing IPR laws for simulating cleantech development: (1) the country's capacities for producing domestic cleantech innovation and for attracting foreign cleantech, (2) the country's need for foreign investment, and (3) the local industries' ability to engage in independent cleantech innovation.

The principal question to ask when designing a national IPR regime is whether the country has acquired basic capacities for producing domestic cleantech innovation or attracting foreign cleantech. If the answer to that question is negative, then the country should focus on capacity building, e.g., through international aid and international cooperation. When the country is relying on international aid for capacity building, unless the international aids attach a string of strong IPR protection, the IPR laws can be relatively weak. This is because at this stage foreign technology owners probably are not strongly motivated to invest in the local market even if the country does offer strong IPR protection. Relatively weak IPR protection may help the domestic industries to legally imitate advanced practices without infringing IPRs. However, adequate IPR protection is necessary when the country has some capacities for cleantech innovation and cleantech importation, and is engaging in some international cooperation activities. This way, the country can protect nascent domestic

[286] Keith E. Maskus, GLOBALIZING INFORMATION: THE ECONOMICS OF INTERNATIONAL TECHNOLOGY TRADE 5 (World Sci. Publ'g Co., 2014).

[287] Ashish Arora, Lee Branstetter, & Chirantan Chatterjee, *Strong Medicine: Patent Reform and the Emergence of a Research-Driven Pharmaceutical Industry in India* 5 (H. John Heinz III Sch. of Pub. Policy & Mgmt. Carnegie Mellon Univ., Conference Draft for Conference on Location of Biopharmaceutical Activity, 2008).

[288] Bernard M. Hoekman, Keith E. Maskus & Kamal Saggi, *Transfer of Technology to Developing Countires: Unilateral and Multilateral Policy Options*, 33(10) WORLD DEV. 1587, 1593 (2005).

[289] *Id*.

cleantech innovation and attract foreign investments, as well as international cleantech cooperation; foreign cleantech owners would feel comfortable to share their cleantech because of the adequate IPR protection in the country. When the country has adequate capacities for domestic cleantech innovation and for attracting foreign cleantech, the country should consider increasing the strength of the IPR laws so IPR can incentivize domestic cleantech innovation, and attract foreign cleantech developers to invest in the country.

The strength of IPR needs to be industry-specific. As the "cleantech" definition provided in the Introduction suggests, cleantech involves a diverse range of technology sectors. Some sectors – e.g., biotech research and engineering of genes that can help crops resist saltation induced by rising sea level—may require strong IPR protection because those industries need significant R&D investments and the products can be easily replicated at low cost. Other sectors – e.g., information technology for managing building energy use – do not need as strong IPR protection as the technologies develop and evolve at a much faster pace, and require less R&D investment.

The table below summarizes the IPR design approaches proposed above for a developing country to develop its domestic cleantech innovation. The terms "weak," "adequate," and "strong" are terms with relativities within the context of a country's IPR regime.

Table 1. Summary of IPR Design Approaches

Development Stage:	**International Aid**	**International Cleantech Cooperation**	**Domestic Cleantech Innovation**
Suggested IPR Strength	Relatively Weak	Adequate	Strong
Reasons	To allow domestic industries to learn advanced practices at low cost. Foreign cleantech owners may yet become interested in the country.	To attract foreign investment, and to assure foreign cleantech owners of their controlling of their cleantech through IPR laws.	To protect domestic cleantech innovation, and to attract international partners to invest in the country and collaborate with the country's domestic industries.

ii. Non-IPR

IPR is just one of the tools available for stimulating cleantech innovation. [290] In addition to clear policies signaling governments' long-term commitment to climate action and sustainable development, as well as the conventional innovation inducement mechanism of IPR, developing countries may also consider using other mechanisms for inducing cleantech innovation. This article specifically advocates the use of various forms of government subsidies (in particular, prizes) and innovation commons.

(a) Prizes

Prizes are a type of subsidy that governments of developing countries may leverage to encourage domestic cleantech innovation.[291] First turning to subsidies in general, subsidies are government economic measures that benefit a particular social group, such as households or firms.[292] They include all cost-reducing or real income-increasing services a government provides to such a group.[293] Subsidies can be ex-ante or ex-post. Ex-ante subsidies are prior inputs to cleantech innovation; the output of specific cleantech innovation from such investment is uncertain.[294] Ex-ante subsidies come in many forms, for example, tax incentives, government grants, and research contracts.[295] Tax incentives include tax credits for cleantech R&D or tax reductions for investments in cleantech innovations.[296] Government-funded cleantech R&D, such as government research grants and contracts to private or academic entities for cleantech R&D, are vital for the development of new cleantech that lacks short-term commercial viability, and is therefore not immediately attractive to the private sector.[297] Governments can also provide tax incentives and subsidies ex-post, conditioning the grant of subsidies upon the recipients generating specific quantities of cleantech innovation output.[298] For example, prizes and government-advanced commitments to purchase specific R&D products are

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[290] Sarnoff, *supra* note 106, at 207.

[291] *Id*.

[292] Warren C. Robinson, *What is a Government Subsidy?,* 20(1) NAT'L TAX J. 86, 87 (1967).

[293] *Id*.

[294] Sarnoff, *supra* note 106, at 207.

[295] *Selected Innovation Prizes & Reward Program* 5 (Knowledge Ecology International, KEI Research Note 2008:1, 2008), https://keionline.org/misc-docs/research_notes/kei_rn_2008_1.pdf [https://perma.cc/5XGB-HM9J].

[296] *Id*.

[297] Jayant A. Sathaye et al., *Overview of IPR Practices for Publicly-funded Technologies*, LAWRENCE BERKELEY NATIONAL LABORATORY 3 (2005), https://escholarship.org/uc/item/7t60d3x6 [https://perma.cc/9VN3-M68T]. Some scholars even regard afore-mentioned IPR laws as a form of ex ante government subsidies; *see* Sarnoff, *supra* note 106, at 209.

[298] Sarnoff, *supra* note 106, at 207.

forms of ex-post subsidies.[299] To enable government subsidies to generate the most effective use or specific outcome, this article suggests increased use of ex-post subsidies.

Next, focusing on prizes in particular, this article considers prizes an important form of ex-post government subsidies for stimulating needed cleantech innovation. Prizes are "rewards provided by the State or a third party in return for a suitably completed invention."[300] Prizes focus on the output of R&D efforts—innovators receive 'prizes' upon fulfilling specific outputs.[301] Governments or non-government entities may offer prizes to stimulate innovations especially needed in specific areas.[302] For example, a government may offer prizes designed to address a particular climate mitigation need – e.g., how to make the local crops more resilient in flooding, which becomes more frequent in certain countries due to climate change.

Prizes may foster cleantech innovation when essential market mechanisms – e.g., carbon pricing or carbon trade – are not yet established.[303] Prizes may be particularly relevant to some developing countries that lack conventional incentives for innovation, such as a strong IPR protection system.[304] A further reason for this article suggests leveraging prizes for cleantech innovation is that prizes may attract diverse participants, instead of limited and pre-identified participants that research grants or research contracts generally do. A potentially broader community of participants may produce unconventional or effective solutions because they will have a broader range of expertise and varying likelihoods of success at the problems that prizes aim to solve.[305]

There is a risk that prizes funded by parties other than the cleantech industries themselves will lack an essential understanding of the relevant cleantech industries, so it will be unable to identify the necessary innovation leaps in the technical fields. Therefore, it is critical for the designers of a prize to closely consult with industry experts and potential contenders for the prize.[306]

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[299] *Id.*

[300] Ted Sichelman, Symposium, *Patents, Prizes, and Property*, 30 HARV. J.L. & TECH. 279, 279 (2017).

[301] Sarnoff, *supra* note 106, at 207.

[302] *Id.*

[303] Richard G. Newell & Nathan E. Wilson, *Technology Prizes for Climate Change Mitigation*, RESOURCES FOR THE FUTURE 3 (Discussion Paper 05-33, 2005), https://www.rff.org/publications/working-papers/technology-prizes-for-climate-change-mitigation/ [https://perma.cc/8L7W-GQXZ].

[304] Reichman et al., *supra* note 185, at 23.

[305] *Selected Innovation Prizes and Reward Programs*, *supra* note 295, at 5; *see also* Reichman et al., *supra* note 185, at 22.

[306] Reichman et al., *supra* note 185, at 22.

(b) Innovation Commons

Commons refers to any resource of which a group of people share access and use.[307] Knowledge commons refers to knowledge as a shared resource, and adopts an institutionalized community approach for governing the production and management of information, science, knowledge, data, and other types of intellectual and cultural resources.[308] This article considers innovation commons as a type of knowledge commons, specifically regarding the management and production of knowledge associated with the innovation.

Modern technology such as the Internet and mobile communication reduced the cost of communication and have connected people together across wide physical distances. In such a networked society, knowledge sharing and collaboration has become simpler and cheaper. As a result, community production has become an increasingly important source of innovation.[309] This article suggests that the government of a developing country should promote the construction of innovation commons in regard to cleantech innovation, and therefore, establish a commons-based approach for cleantech innovation, paralleling the conventional IPR approach. A government can construct cleantech related innovation commons in several ways.[310] For example, a government can create or fund the creation of information databases on patents and scientific literature concerning cleantech. This way, instead of conducting their own research or paying experts for gathering such information, local innovators may access the information databases provided by the government.

Additionally, a government may also promote various practices of innovation commons through open innovation and peer production. First looking at open innovation, open innovation is a form of business collaboration.[311] It utilizes knowledge shared across various participants in a market, including companies, individuals, suppliers, distributors, academia, and others, to solve common problems and to assist the participants' internal innovation.[312] For example, to

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[307] Charlotte Hess & Elinor Ostrom, *Introduction: An Overview of the Knowledge Commons*, in UNDERSTANDING KNOWLEDGE AS A COMMONS (C. Hess & E. Ostrom, eds., MIT Press, 2007).

[308] Workshop on Governing Knowledge Commons, *An Introduction to Knowledge Commons*, KNOWLEDGE-COMMONS (Aug. 2014), http://knowledge-commons.net/downloads/Knowledge%20Commons%20Description.pdf [https://perma.cc/5ET9-Y63H].

[309] Yochai Benkler, *Law, Innovation & Collaboration in Networked Economy & Society*, 13 ANNU. REV. LAW SOC. SCI. 231, 232 (2017).

[310] *See, e.g.*, Neil D. Gordon et al., *The Polar Prediction Project*, WORLD METEOROLOGICAL ORG. (last visited Oct. 27, 2019), https://public.wmo.int/en/resources/bulletin/polar-prediction-project [https://perma.cc/7768-CYUF]. Existing knowledge commons concerning climate and environments: For example, World Meteorological Organization's data on polar climate conditions, Conservation Commons re biodiversity.

[311] Benkler, *supra* note 309, at 232.

[312] *See id.*

detect wildfires that are occurring more frequently in the warmer climates, Cellnex Telecom, the main independent infrastructure operator for wireless telecommunication in Europe, organized an engineering competition, which brought together 36 engineers from 18 different countries and resulted in two fully new prototypes for early detection of fire.[313] Linux Foundation – a leading advocator for open source movement—collaborated with RTE, Europe's biggest transmission power systems provider, and other organizations, to conduct multi-vendor collaboration and open source progress in the energy and electricity sectors so as to accelerate the use of information technologies that are critical to efficient energy use.[314] Next turning to peer production, peer production occurs when individuals pool their knowledge and resources together and coordinate their actions toward common goals, eliminating the involvement of firm hierarchies or market.[315] In peer production, information is available as an open-access commons. Any person who recognizes a problem may identify it; any person who has the time, training, and insight to offer a solution or response could do so; the network of participants could verify, test, and evaluate the quality of the various solutions.[316] Examples of peer production include the open-source software movement and Wikipedia.[317]

A government can promote innovation commons in at least two ways. First, a government can manage an innovation commons created with private data or informal commons created with government-sponsored information and other outputs.[318] Second, a government can subsidize and control private sector commons by regulating inputs to the commons and outputs from the commons, access to the commons and other terms of interaction.[319] A government may also compel cooperation and participation on commons, and choose to limit the application of regulations that may limit commons development.[320]

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[313] Mario Honrubia, *5 Successful Open Innovation Examples You Can Learn Something From,* ENNOMOTIVE (Aug. 6, 2018), https://www.ennomotive.com/open-innovation-examples/ [https://perma.cc/S4EU-4G9P].

[314] Press Release, The Linux Foundation, The Linux Foundation Launches LF ENERGY, New Open Source Coalition (July 12, 2018) (on file with author), https://www.linuxfoundation.org/press-release/2018/07/the-linux-foundation-launches-lf-energy-new-open-source-coalition/ [https://perma.cc/55P7-F429].

[315] Yochai Benkler, *Coase's Penguin, or, Linux, and "The Nature of the Firm,"* 112(3) YALE L.J. 369, 375 (2002); Carliss Baldwin & Eric von Hippel, *Modeling a Paradigm Shift: Producer Innovation to User and Open Collaborative Innovation* 16 (MIT Sloan Sch. Mgmt., Working Paper No. 4764-09, Harvard Bus. Sch. Fin., Working Paper No. 10-038, 2010), http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1502864 [https://perma.cc/D6SW-9RBM].

[316] Benkler, *supra* note 309, at 9.

[317] Benkler, *supra* note 315, at 372-373.

[318] Sarnoff, *supra* note 106, at 215.

[319] *Id.* at 215.

[320] *Id.*

The above discussion for non-IPR innovation tools only covers what the article considers the most important means to stimulate domestic cleantech innovation. Other available tools include such as various government regulations on the cleantech market – e.g., competition regulations concerning market structure and operations of different cleantech sectors, and on cleantech product and process – e.g., recognition and certification programs.[321]

C. *Evaluation of the Proposal*

An immediate critique to this proposal is that one should not insist on domestic cleantech innovation by developing countries. This view points to the fact that developed countries have a concentration of innovation capacities, and developing countries have a concentration of production capacities with much lower manufacturing costs.[322] This view favors the partnership opportunity between developed countries and developing countries, leveraging the current advantages each group has. "This potential partnership requires open markets and open investment regimes around the world," and "build[s] an environment attractive to Western multinationals, productive for host countries, and open to trade."[323] This view recommends the establishment of a global innovation system, instead of individual domestic innovation systems.

This article's responds by asking, if individual countries cannot set up local capacities for innovation, how would a global-scale innovation system, with entails much more complexity and requires much more coordination, assure success? Further, such a global innovation system would likely perpetuate developing countries' dependency on developed countries. The limited success of international cleantech transfer since the 1970s, as discussed in Part I.B, illustrates that such dependency does not provide effective climate actions and sustainable development.

Another critique to this article's proposal suggests that developing countries need to integrate themselves into global value chains ("GVCs"). Global value chains comprise intermediate goods and services with cross-border trade of inputs and outputs that take place through multinational corporations' networks of affiliates, contractual partners and suppliers. GVCs nowadays account for about 80 percent of global trade.[324] According to UNCTAD, global value chains currently contribute nearly 30 percent to the GDP of developing countries.[325]

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[321] *Id*. at 217.

[322] Branstetter, *supra* note 27, at 22-23.

[323] *Id*.

[324] Press Release, United Nations Conference on Trade & Development [UNCTAD], 80% of trade takes place in 'value chains' linked to transnational corporations, UNCTAD report says, U.N. Press Release UNCTAD/PRESS/PR/2013/001 (Feb. 27, 2013), https://unctad.org/en/pages/PressRelease.aspx?OriginalVersionID=113 [https://perma.cc/T3UJ-3ECK].

[325] U.N. Conference on Trade and Development, *World Investment Report 2013*, xxii, U.N. Doc. UNCTAD/WIR/2013 (2013).

The article agrees that developing countries must integrate well into GVCs that benefit the countries' overall development. However, not all GVCs are beneficial in such a way, at least currently. In the meantime, integration into GVCs requires developing countries to upgrade their production capacities, such as human capital. An empirical exercise conducted by the World Bank indicated the adverse impact of GVCs on developing countries' comparative advantages. GVCs demand skills and capabilities that are in short supply in developing countries, and undercut their traditional comparative advantage in unskilled labor.[326] Further, studies of GVCs in East Asian countries have found that, while local firms can leverage learning from GVC participation to extract sector- and economy-wide effects, the learning effects were made possible mainly because of supportive in-country institutions and cohesive policy frameworks to promote innovation and capabilities building.[327] Therefore, for developing countries to well integrate into GVCs, developing countries need to upgrade their capacities for productions and innovation, which go in line with the proposal of the article that developing countries need to build their local capacities for attracting foreign cleantech and domestic cleantech innovation. On the other hand, as illustrated by the ongoing Covid-19 pandemic that has ravaged the global community, over reliance on the GVCs may impact a country's timely response to domestic emergencies.

CONCLUSION

Global cleantech development and deployment is critical for climate action and sustainable development. While the one-way voluntary transfer of cleantech from developed countries to developing countries is necessary, and the effort to improve it should continue, this article proposes that we should emphasize global cleantech development and deployment and enable developing countries to build their own cleantech innovation systems. This way, we can make climate action sustainable successes and sustainable development a sustainable reality down the road. Specifically, this article proposes a pathway for enabling cleantech innovation by developing countries. The pathway includes three phases: international aid, mutually beneficial international cleantech cooperation, and domestic cleantech innovation. This article suggests that the global community enables developing countries to move toward domestic cleantech innovation via international aid and mutually beneficial international cleantech cooperation, so to enhance developing countries' capacities for cleantech importation and cleantech innovation, to integrate well into a potential

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[326] Dani Rodrik, *New Technologies, Global Value Chains, and the Developing Economies* 5 (Pathways for Prosperity Commission, Background Paper Series No. 1, 2018), https://drodrik.scholar.harvard.edu/files/dani-rodrik/files/new_technologies_global_value_chains_developing_economies.pdf [https://perma.cc/K7ZP-AZ5U].

[327] Padmashree Gehl Sampath & Bertha Vallejo, *Trade, Global Value Chains and Upgrading: What, When & How?*, 30(3) EUR. J. DEV. RES. 481, 483 (2018).

global innovation system and the currently prevalent global value chains. This article also suggests developing countries build up their domestic innovation systems by sending clear and persistent policy signals encouraging cleantech investment, e.g., by private sectors, and by employing diverse innovation tools for cleantech development and deployment; such tools include customized national IPR regime for cleantech and non-IPR innovation tools such as prizes and innovation commons.

APPENDIX

Table 2. World Bank Year 2020 Classification of Economies (By Per Capita Gross National Income in Year 2018)

High Income	Upper Middle-Income	Lower Middle-Income	Low Income
Andorra	Albania	Angola	Afghanistan
Antigua and Barbuda	Algeria	Bangladesh	Benin
Aruba	American Samoa	Bhutan	Burkina Faso
Australia	Argentina	Bolivia	Burundi
Austria	Armenia	Cabo Verde	Central African Republic
Bahamas, The	Azerbaijan	Cambodia	Chad
Bahrain	Belarus	Cameroon	Congo, Dem. Rep.
Barbados	Belize	Comoros	Eritrea
Belgium	Bosnia and Herzegovina	Congo, Rep.	Ethiopia
Bermuda	Botswana	Côte d'Ivoire	Gambia, The
British Virgin Islands	Brazil	Djibouti	Guinea
Brunei Darussalam	Bulgaria	Egypt, Arab Rep.	Guinea-Bissau
Canada	China	El Salvador	Haiti
Cayman Islands	Colombia	Eswatini	Korea, Dem. People's Rep.
Channel Islands	Costa Rica	Ghana	Liberia
Chile	Cuba	Honduras	Madagascar

High Income	Upper Middle-Income	Lower Middle-Income	Low Income
Croatia	Dominica	India	Malawi
Curaçao	Dominican Republic	Indonesia	Mali
Cyprus	Ecuador	Kenya	Mozambique
Czech Republic	Equatorial Guinea	Kiribati	Nepal
Denmark	Fiji	Kyrgyz Republic	Niger
Estonia	Gabon	Lao PDR	Rwanda
Faroe Islands	Georgia	Lesotho	Sierra Leone
Finland	Grenada	Mauritania	Somalia
France	Guatemala	Micronesia, Fed. Sts.	South Sudan
French Polynesia	Guyana	Moldova	Syrian Arab Republic
Germany	Iran, Islamic Rep.	Mongolia	Tajikistan
Gibraltar	Iraq	Morocco	Tanzania
Greece	Jamaica	Myanmar	Togo
Greenland	Jordan	Nicaragua	Uganda
Guam	Kazakhstan	Nigeria	Yemen, Rep.
Hong Kong SAR, China	Kosovo	Pakistan	
Hungary	Lebanon	Papua New Guinea	
Iceland	Libya	Philippines	
Ireland	Malaysia	São Tomé and Principe	
Isle of Man	Maldives	Senegal	
Israel	Marshall Islands	Solomon Islands	
Italy	Mauritius	Sudan	
Japan	Mexico	Timor-Leste	
Korea, Rep.	Montenegro	Tunisia	

High Income	**Upper Middle-Income**	**Lower Middle-Income**	**Low Income**
Kuwait	Namibia	Ukraine	
Latvia	Nauru	Uzbekistan	
Liechtenstein	North Macedonia	Vanuatu	
Lithuania	Paraguay	Vietnam	
Luxembourg	Peru	West Bank and Gaza	
Macao SAR, China	Romania	Zambia	
Malta	Russian Federation	Zimbabwe	
Monaco	Samoa		
Netherlands	Serbia		
New Caledonia	South Africa		
New Zealand	Sri Lanka		
Northern Mariana Islands	St. Lucia		
Norway	St. Vincent and the Grenadines		
Oman	Suriname		
Palau	Thailand		
Panama	Tonga		
Poland	Turkey		
Portugal	Turkmenistan		
Puerto Rico	Tuvalu		
Qatar	Venezuela, RB		
San Marino			
Saudi Arabia			
Seychelles			
Singapore			

High Income	**Upper Middle-Income**	**Lower Middle-Income**	**Low Income**
Sint Maarten (Dutch part)			
Slovak Republic			
Slovenia			
Spain			
St. Kitts and Nevis			
St. Martin (French part)			
Sweden			
Switzerland			
Taiwan, China			
Trinidad and Tobago			
Turks and Caicos Islands			
United Arab Emirates			
United Kingdom			
United States			
Uruguay			
Virgin Islands (U.S.)			