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Working Paper

Climate change & technology transfer: Barriers, technologies and mechanisms

Working Paper, No. 382

Provided in Cooperation with:

Indian Council for Research on International Economic Relations (ICRIER)

Suggested Citation: Goldar, Amrita; Sharma, Shubham; Sawant, Viraj; Jain, Sajal (2019) : Climate change & technology transfer: Barriers, technologies and mechanisms, Working Paper, No. 382, Indian Council for Research on International Economic Relations (ICRIER), New Delhi

This Version is available at:

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Working Paper 382

Climate Change & Technology Transfer – Barriers, Technologies and Mechanisms

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July 2019



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Acknowledgements

In carrying out this research, we have benefited from the experience of various experts in the field and we would like to thank them for devoting their time and energy to engage with us. We would like to thank Dr. Rajesh Katyal (Director General, National Institute of Wind Energy), Mr. R. V. Sundararaman (Director/Engineering, Tamil Nadu Electricity Regulatory Commission), Prof. Rajan N. K. S. (Chief Scientist, Combustion Gasification Propulsion Laboratory, Indian Institute of Science), Prof. T. Sundararajan (Department of Mechanical Engineering, Indian Institute of Technology, Madras), Prof. P. Balachandra (Principal Research Scientist, Department of Management Studies, Indian Institute of Sciences), Dr. Jai Asundi (Research Co-ordinator, Centre for Study of Science, Technology & Policy), Mr. R. Kulothungan (Senior Vice President, Biomass Business, Orient Green Power Company Limited), Mr. Sreekrishna Sankar (CEO, Director, Green Power Systems), Mr. Joseph Vimal Arulappan (CEO, FOV Biogas India Pvt. Ltd.), Mr. Yuvraj Sarada (Business Development & Strategy, SunMobility), Mr. Tarun Mehta (Co-founder and CEO, Ather Energy) and Ms. Relina D'Silva (Associate Manager, Ather Energy Pvt. Ltd.) for sharing their expertise in their domains. We thank Dr. O. P. Wali (Professor, Centre for International Trade in Technology, Indian Institute of Foreign Trade), Mr. Nitya Nanda (Associate Director, Resource Efficiency and Governance, TERI), Mr. Souvik Bhattacharya (TERI), Mr. Durgesh Rai (Research Associate, ICRIER), and Dr. Saon Ray (Senior Fellow, ICRIER) for their valuable contribution.

We are grateful to Prof. Rangan Banerjee (Head of Department, Energy Science and Engineering, Indian Institute of Technology Bombay) and Mr. Debasish Mallick (Deputy Managing Director, Export Import Bank of India), for their constructive inputs, which has helped enhance the quality of this report. Lastly, we would like to thank Dr. Rajat Kathuria (Director & Chief Executive, ICRIER) for his constant support and encouragement to our research endeavours.

Abstract

Technology transfer is one of the most contentious issues in international negotiations on climate change. Despite its recognition at international platforms such as the United Nations Framework Convention on Climate Change, G20, etc., the independent review of Climate Technology Centre and Network (CTCN), the operational arm of the UNFCCC's Technology Mechanism, shows the lack of success in the transfer of environmentally sound technologies.

This study examines the barriers to technology transfer and suggests strategies to improve current technology transfer frameworks. While finance is the biggest barrier stated by countries worldwide, the ability to absorb technologies is an equally important factor as is evident from case studies from India. Apart from finance, barriers could arise due to the mode of transfer, the nature of technologies, the sectors (such as energy and transport) in which such technology is sought, intellectual property rights, etc.

The study analyses the OECD patent database for G20 countries to identify dominant sectors and technologies. Energy and transport stand out in terms of the number of patents filed signifying the flow of technical expertise (R&D) and finances in these sectors while sectors such as agriculture, natural resource management, disaster resilience, etc., have not attracted much attention. The study also assesses current initiatives to determine India's technological needs and presents an overview of the initiatives undertaken by the Government of India to promote diffusion of environmentally sound technologies.

The study finds that the success of technology transfer depends heavily on the availability of funds, absorption capacity of the recipient country and the differential treatment of technologies in technology transfer frameworks.

Key words: *Climate Change, Environmentally Sound Technologies, Technology Transfer, Financial Barriers, Absorption Capacities, Patent Growth, Emerging Economies.*

JEL classification: *O32, O44, Q01, Q54, Q55*

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Climate Change & Technology Transfer – Barriers, Technologies and Mechanisms

Amrita Goldar, Shubham Sharma, Viraj Sawant and Sajal Jain

1 Introduction

The wide consensus on curbing climate change has led to initiatives at the country and global level through platforms such as the United Nations Framework Convention on Climate Change (UNFCCC). Industrialisation, responsible for anthropogenic emission of greenhouse gases (GHGs), has been characterised by the introduction of new technologies and a widely discussed view is that if the introduction of technologies created the problem, other new technologies will help resolve it. Such technologies already exist, but not yet in the countries where they

Box 1

Role of Technology: Phasing out of CFCs – Montreal Protocol

According to a NASA study published in the journal 'Geophysical Research Letters' earlier this year (January 4th), the ozone hole is recovering. It is the first direct proof of recovery based on the measurements of the chemical composition inside the ozone hole to confirm that not only is ozone depletion decreasing, but that the decrease is caused by a decline in chlorofluorocarbons (CFCs). The recovery of the ozone layer is testimony to what international co-operation can achieve. It is also important to understand the role of technology that enabled the phasing out of CFCs, which was primarily responsible for the ozone hole. In the late 1970s, DuPont was the world's major producer of CFCs (Freon), with a 25 per cent market share. In 1980, the company patented HFC-134a, the leading CFC alternative, subsequently filing more than 20 patents before and after the Montreal Protocol¹. The development of alternatives to CFCs resulted in the reduction of CFCs in the atmosphere. The success of the Montreal protocol is the result of co-ordinated regulatory and technological development.

could be more potent and are required to mitigate climate change.² Technology transfer,³ which is expected to bridge this gap, has been one of the avenues discussed in international climate change negotiations to enhance resilience to climate change. It is a long-standing issue in the United Nations' climate change negotiations, rooted in Article 4 of the UNFCCC (Rio Earth

¹ The Montreal Protocol is a global agreement, reached in 1987, to protect the stratospheric ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS).

² IPCC- Special Report - Methodological and Technological Issues in Technology Transfer <https://www.ipcc.ch/report/methodological-and-technological-issues-in-technology-transfer/> accessed on February 01, 2018

³ IPCC's report on *Methodological and Technological Issues in Technology Transfer* defines the term "technology transfer" as a broad set of processes covering the flows of knowhow, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, NGOs and research/educational institutions.

Summit, 1992). Technology transfer requires international co-operation among countries for sustainable development, especially in emerging economies and least developed countries.

Developing countries have experienced a rapid increase in their CO₂ emissions since the 1990s. CO₂ emissions have risen sharply in emerging economies with China almost quadrupling its emissions with an increase of 364 per cent while India (278 per cent), Indonesia (215 per cent) and Saudi Arabia (202 per cent) have also increased their emissions considerably. Developing countries need to look for low emission pathways of economic development to combat climate change.

Recent technological innovations in renewable energy technologies have been responsible for the success of global efforts to limit GHG emissions and have made possible the transition to a low carbon economy (Schmidt & Sewerin, 2017). But most of these innovations are concentrated in a few developed countries. For example, in the case of environmentally sound technologies (as defined by OECD), most of the innovations (measured in terms of the number of patents) are concentrated in the United States, Japan, South Korea and Germany. Hence, it is imperative to promote technology transfer from developed countries to developing and under-developed countries to mitigate climate change, which is a global concern.

This study examines the importance, the benefits, and the conceptual aspects of, and the current mechanisms for technology transfer as well as the barriers to such transfer by reviewing existing literature and case studies from India.

2 Importance of Technology Transfer

The objective of Article 2 of the UNFCCC is to stabilise GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interferences with the climate system.⁴ The accomplishment of this objective would require technological innovations, including the development of knowhow for mitigation of greenhouse gas (GHG) emissions and adaptation to climate change that needs to be diffused rapidly and widely.⁵ International negotiations too, therefore, have stressed the need for technology transfer.

2.1 UNFCCC and Other Relevant Conventions and Agreements

UNFCCC includes provisions for the development and transfer of technology in article 4.5 and 4.7. Article 4.5 states that the developed country parties in Annex I and II should take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of or access to environmentally sound technologies and knowhow to other parties, particularly developing country parties, to enable them to implement the provisions of the Convention. Article 4.7 underlines the dependence of developing countries on the availability of financial resources

⁴ UNFCCC- Article 2, Objective of the convention:

<https://unfccc.int/resource/docs/convkp/conveng.pdf> accessed on March 08, 2018

⁵ IPCC – Special Report- Methodological and Technological Issues in Technology Transfer

<https://www.ipcc.ch/pdf/special-reports/spm/srtt-en.pdf> accessed on March 08, 2018

and transfer of technologies to implement the convention commitments effectively. A set of agreements – the Marrakech Accords – reached at the Conference of Parties (COP) 7 (Marrakech) held in 2001, decided to adopt a framework for meaningful and effective actions to enhance the implementation of Article 4.5 of the convention and to establish an expert group on technology transfer.⁶ Negotiations for the mechanism started at COP 13 (Bali, 2007) in the hope that the process would eventually lead to a formal decision or understanding at COP 15 (Copenhagen, 2009). The Global Environment Facility (GEF) at COP 14 (Poznan, 2008) was entrusted with the task of developing a strategic programme aimed at scaling up technology transfers to developing nations.⁷

Table 1: Summary of UN Negotiations

Year	COP/Summit	Key Outcome/ Mandate
1992	Rio, Earth Summit	Technology development and diffusion – Fourth Commitment of the parties in Article 4
1995	Berlin, COP1	Establishing an inventory of technology transfer projects; investigating technology transfer financing; establishing networks of technology centres and identifying needed adaptation technologies
1997	Kyoto, COP3	Decision to consult with the Global Environmental Facility (GEF) and other relevant international organisations to support the work of (an) international technology information centre(s)
1998	Buenos Aires, COP4	Buenos Aires plan of action – called on industrialised countries to provide lists of publicly-owned, environmentally sound technologies and on developing countries to submit reports outlining their technological needs
1999	Bonn, COP5	Subsidiary Body for Scientific and Technological Advice (SBSTA) to hold consultations among parties and outcome of the process to incorporate a draft text on a framework for meaningful and effective actions to enhance the implementation of Article 4.5 of the Convention
2001	Marrakech, COP7	Adopted technology framework; established expert group on technology transfer (EGTT)
2002	New Delhi, COP8	SBSTA to conduct consultations and facilitate collaboration among expert groups established under the Convention, to the extent practicable, on their work programmes on cross-cutting issues, including those relating to technology transfer and capacity-building activities
2004	Buenos Aires, COP10	Encourage parties to undertake joint research and development programmes/projects between Annex II parties and parties not included in Annex I.

⁶ UNFCCC- Relevant Conventions: https://unfccc.int/files/meetings/workshops/other_meetings/application/pdf/wanna.pdf accessed on March 08, 2018

⁷ CSE note on Technology Transfer: <http://www.cseindia.org/userfiles/Technology%20transfer.pdf> accessed on March 08, 2018

Year	COP/Summit	Key Outcome/ Mandate
2006	Nairobi, COP12	Extension of EGTT for one year including its current membership
2007	Bali, COP13	Identify technology as one of the four pillars of an expected post-2012 climate change regime; collaborative research and development
2008	Poznań, COP14	Strategic programme on technology transfer; provision for Global Environment Funding for climate technology development and transfer activities
2010	Cancún, COP16	Establishment of a Green Climate Fund and a fully operational technology mechanism to promote innovation by 2012; setting up the Technological Executive Committee (TEC) and Climate Technology Centre & Network (CTCN); conclusion of EGTT's role
2011	Durban, COP17	Arrangements to make the technology mechanism fully operational in 2012
2012	Doha, COP18	Arrangements to make the Climate Technology Centre and Network (CTCN) fully operational, report of the Technology Executive Committee (TEC) and enhanced action on the provision of financial resources and investment to support action on mitigation and adaptation and technology co-operation
2013	Warsaw, COP19	Adoption of the modalities and procedures of the CTCN
2015	Paris, COP21	Paris Agreement, to identify linkages between the technology mechanism and the financial mechanism of the Convention, and to enhance climate technology development and transfer through the technology mechanism
2017	Bonn, COP23	Report on the independent review of the effective implementation of the CTCN and renewing the memorandum of understanding between the Conference of the Parties and the United Nations Environment Programme regarding the hosting of the Climate Technology Centre
2018	Katowice, COP24	Requested subsidiary body for implementation to assess progress in strengthening the linkages between the technology mechanism and the financial mechanism to recommend a draft decision on strengthening the technology mechanism and financial mechanism linkages for consideration and adoption at COP26.


Source: Prepared by authors from <https://unfccc.int/ttclear/negotiations/decisions.html> accessed on June 13, 2019

Clearly, the UNFCCC and parties recognise the importance of technology transfer and stress the need for co-operation among developed and developing countries.

2.2 Merits of Technology Transfer

Before assessing the benefits of technology transfer, an understanding of the broad channels of technology transfer is necessary. This will help identify the benefits of transfer through different channels. This report uses the taxonomy of technology transfer provided by Lema & Lema (2016) that defines ‘organisational arrangements’ to facilitate technology transfer. Importing equipment and foreign direct investment (FDI) are conventional organisational arrangements whereas joint research collaborations and strategic acquisitions are examples of unconventional organisational arrangements that enable technology transfer. The taxonomy builds upon four variables that define these organisational arrangements. These four variables are ‘location of equipment production’, ‘ownership of equipment’, ‘origin of proprietary technology’, and ‘ownership of proprietary technology’. The table below describes the various types of technology transfer mechanisms.

Table 2: Illustration of Technology Transfer Mechanisms and Technology Transfer Flows

Interaction and recipient effort		Mechanisms	Location of equipment production	Ownership of equipment manufacturer	Origin of proprietary technology	Ownership of proprietary technology
Low 	Conventional	1. Trade Import of hardware developed and produced outside the host country	External	External	External	External
		2. Foreign Direct Investment (FDI) Establishment by a foreign MNC of a wholly-owned subsidiary in the host country	Internal	External	External	External
		3. Joint Venture Equity association between an MNC and a local firm in which the MNC typically contributes proprietary technology	Internal	Shared	External	External
High						

Interaction and recipient effort		Mechanisms	Location of equipment production	Ownership of equipment manufacturer	Origin of proprietary technology	Ownership of proprietary technology
		4. Licensing Agreement Transfer of intellectual property from a foreign firm (licensor) to a local firm (licensee)	Internal	Internal	External	External/ conferred
	Unconventional	5. Strategic acquisitions and alliances Controlling purchase or non-equity alliance with foreign firms	Internal	Internal	External	Internalised
		6. Overseas R&D R&D conducted in-house by a local firm in a foreign country	Internal	Internal	External	Internal
		7. Joint R&D R&D conducted jointly between a local and a foreign firm	Internal	Internal	Internal or external	Shared
	Local	8. Local Innovation Local firm with own proprietary technology developed through in-house R&D and/or local technology linkages	Internal	Internal	Internal	Internal

Source: Lema & Lema, 2016

These organisational arrangements – trade, FDI, joint ventures, collaborative research and development, etc. – allow firms in developed countries to access emerging markets and thus ensure overall economic prosperity. In the case of climate change, the transfer of technologies

is important to achieve scale economies and to enable developing countries to follow a low-carbon pathway to economic development.

2.2.1 Developing Countries

It has been established that technological advancement and economic growth go hand in hand. Today, developing countries face the dual challenge of combating climate change and achieving economic growth simultaneously. These countries lack the technological sophistication required to deal with this challenge. If these countries depended solely on indigenously developed technology, it would take much longer for them to achieve the level of technological advancement that developed countries already have, delaying global action to address climate change. Thus, technology transfer from developed countries to developing countries becomes a crucial component of a climate action plan. While technology transfer will enable developing countries to meet their developmental needs and

international climate change commitments, the success of technology transfer will depend heavily on appropriate choice of channels for technology transfer and the strength of innovation systems in the recipient countries. There are several channels of technology transfer identified in existing literature. It is necessary to assess the technology transfer narrative carefully, using past experience to identify the most effective channels. A lot can be learnt from China's experience in developing its renewable energy technology sector. Additionally, different types of technologies require different types of policies to enable them to reach the level of commercial deployment. Manufacturing of renewable energy technology can be divided into three types: (i) mass produced standardised goods (e.g. solar PV) (ii) complex engineered products (e.g., wind turbines) and (iii) complex product systems (e.g., biomass power plant) (Binz, Gosens, Hansen, & Hansen, 2017). Even though different policies are needed for the development of these technologies, Chinese experience tells us that all these industries benefited from international technology transfer. The solar PV industry in its initial stages

Box 2

Experience of late comer solar PV companies: Evidence from China

Suntech, a leading solar panel manufacturer, has adopted a mixed strategy of conventional, unconventional, and local mechanisms of technology transfer and absorption. It has formed joint ventures, undertaken technology licensing and overseas R&D efforts in Germany and Australia, and acquired foreign firms. It has a licensing agreement with Germany-based SolarWorld. It has innovation capabilities worldwide with 450 people employed in R&D in four continents. It has filed more than 200 patents. Suntech collaborates with five Chinese and some overseas universities like the University of New South Wales, and the Swinburne University of Technology.

One of the leading solar panel manufacturers, **Yingli Solar**, also adopts a diverse set of organisational arrangements. With its PV testing lab in San Francisco, a research subsidiary in Spain and a similar facility in Singapore, Yingli combines local R&D effort with international partners. Yingli has also partnered up with US solar firm Amtech and the Netherlands based Energy Research Centre for solar panel technology advancement. It has so far filed more than 700 patents.

benefited from technology support from developed countries such as Germany and the United States. It is only later that Chinese firms started innovating on their own and shed their dependence on technologies from abroad. The biomass power plant industry in China benefited from technology licensed from Denmark.

However, domestically in China, the development of these three industries differed. The mass-produced standardised goods industry benefited from bottom-up policies (such as incentivising private-private partnerships); complex product systems needed a top-down approach (involving government-led joint ventures) while complex engineered products required a mix of both.

There is definitive evidence to suggest that technology sharing between developed and developing countries helps the latter develop their technological sector and, if done right, strengthens their innovation systems. Technology transfer becomes a capacity building exercise through diffusion of benefits over the entire supply chain. In the case of China, the labour force greatly benefited from the development of industries in the solar and wind energy sectors through acquired skills, and firms increased their innovation capabilities. The result is that China accounts for most of the recent patents in solar PV manufacturing. Technology transfer has several benefits for developing nations and they need to adopt the right mix of policies to capitalise on these gains.

2.2.2 Developed Countries

The objective of the UNFCCC is to limit global emission of green house gases; cost effectiveness, environmental effectiveness, equity and contribution to economic growth and sustainable development are important criteria for deciding emission reduction options. Technology transfer fulfils these criteria and, more importantly, is necessary for achieving equitable and sustainable global growth. The current level of prosperity and growth achieved by developed countries has been the result of the industrial revolution and the excessive use of fossil fuels. The newly emerging economies cannot be held responsible for the current levels of GHGs in the atmosphere, even though they are more vulnerable to the resultant climate change. This view has been accepted and endorsed by the adoption of the principle of common but differentiated responsibilities in the first Rio earth summit.⁸ In order to meet their reduction commitments, it becomes imperative for developed countries to direct their resources in the form of finances, information and technologies to developing countries.

The most preferred option for technology sharing is through business partnerships of various kinds for exporting technology to or setting up a manufacturing facility in the receiving country ('organisational arrangements'). Developing countries offer attractive growth opportunities for companies in developed countries. Besides, labour is comparatively cheap in developing countries like India, enabling companies from developed countries to benefit from lower costs

⁸ Rio Declaration On Environment and Development:
<http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm> accessed on March 20, 2018

if they decide to get into joint ventures or set up manufacturing facilities in developing countries.

Despite the benefits of technology transfer outlined above, the current technology transfer frameworks have not been able to achieve the desired level of success (discussed later in the study) primarily due to the barriers impeding the flow of technology from developed countries to developing countries.

Box 3

Importance of adapting technology to local circumstances

Technologies for enhancing climate resilience can be divided broadly into two categories: matured technologies that have been sufficiently developed and commercialised like solar panels and wind turbines, and emerging technologies that have significant potential for advancement in terms of economic affordability and efficiency like electric mobility technologies or bio-energy technologies. The ideal way for companies that own these technologies to enter developing countries is to find local partners through a mix of conventional and unconventional organisational arrangements (Table 3). Evidence suggests that the local contexts of these countries are extremely crucial for adoption of technologies even in the case of matured technologies. This is clearly demonstrated when one examines closely the case of technologies in the bio-energy and electric mobility sectors.

Bio-energy technologies are an effective way to manage different kinds of waste like agricultural waste and urban wet waste and convert them into energy. These technologies are fairly matured in the western world. Countries like Sweden, Norway and Denmark have worked extensively on developing these technologies and have successfully adopted the use of these technologies domestically. However, the adoption of these technologies is tricky in developing countries where transaction costs, and hence, fuel costs are high. Interactions with representatives of the bio-energy industry in India reveal that directly importing industrial scale reactors into India from western countries has not been very successful. It is companies that have studied the local context and have done their own R&D to customise the technology to match local needs that have survived and managed to set up economically viable bio energy projects in India. Thus, it is beneficial for companies in developed countries to get into joint ventures and collaborative R&D so that their products and technologies have the best chance of getting absorbed in some of the world's largest and rapidly growing markets.

The need to take into account the local context is also evident in the case of technologies associated with electric mobility. In the US and Europe, where the penetration of personal vehicles is very high, the electric mobility business focuses on business models for personal EVs (electric vehicles). This, however, cannot be replicated in countries like India where the population is high and where high penetration of personal vehicles will result in crowded and uninhabitable urban spaces. Thus, electric mobility companies have started focusing on electrification and growth of public transport. Technologies developed by companies in western countries need to be modified and customised to improve the suitability of electric mobility for public transport applications. Local partners are valuable in undertaking such customisations and can contribute meaningfully to developing these technologies further. Therefore, it is in the interest of developed countries to engage constructively with local partners.

3 Barriers to Technology Transfer

The success of technology transfer depends on socio-economic factors. In general, technology transfers are characterised by both hardware elements and software elements (such as education and training).⁹ With several stakeholders involved, the process of technology transfer can be complex but there are identifiable stages. These stages may include the identification of needs, choice of technology, assessing conditions of transfer, agreement and implementation. Barriers to environmentally sound technologies (ESTs) may arise at any of these stages. These barriers could be generic in nature or could be specific to the sector or technologies. Before discussing these barriers in detail, one must understand the components, flow and channels of technology transfer.

Flow of Technology Transfer and major channels

As discussed earlier, the major channels for technology transfer are international trade in intermediate goods, foreign direct investments (including joint ventures) and licensing. The diffusion mechanism in each of these channels and, hence, the extent of knowledge transfers, may vary. The import of capital goods that embodies technology, for example machinery and equipment, results in technology transfer ushering productivity benefits in the recipient countries. Such transfers at times result in knowledge spill-overs where local firms can reverse-engineer imported capital goods (equipment and machinery), or acquire knowledge through business relationships by being part of a global value chain. For example, China purchased turnkey production lines from German, US and Japanese suppliers and developed a high-performing solar photovoltaic industry by acquiring production technologies in the process (De La Tour & Glachant, 2011).

Foreign direct investment (FDI) results in more technology transfer than trade in goods as knowledge/technology resides in the recipient country. Such transfers are more potent in the case of joint ventures as the local partner has direct access to the technology. FDI, as literature suggests, has been the key driver of technology transfer in the wind power industry (Kirkegaard, Weischer, & Hanemann, 2009).

Another channel for technology diffusion is licensing, which probably is the most direct, where corporations or public research bodies grant a patent licence to an organisation. Licensing is a very common practice for domestic technology transfer from research institutes to industries. In licensing, the knowledge leaves both the source country and the source company. Practically, international licensing has been preferred mostly in the following three sectors: chemicals, drugs, and electronics and electrical equipment (Glachant & Dechezeleprêtre, 2017). However, licensing is not suitable for all products or industries and may prove costly for firms in developing countries to acquire.

⁹ UN Background paper on Climate Change: Technology Development and Technology Transfer: https://sustainabledevelopment.un.org/content/documents/1465back_paper.pdf accessed on April 02, 2018

Before going into the barriers, it is important to understand what is meant by technology. As has been mentioned earlier, IPCC defines technology as a piece of equipment, technique, practical knowledge or skills to perform a particular activity. The three dominant components of any technology are:

- **Hardware:** Equipment, machinery, products, etc.
- **Software:** the knowledge of processes of production and use of hardware, manuals and skills, experience, training, etc.
- **Orgware:** Institutional framework, or organisation, involved in the adoption and diffusion of a technology

All three components are embedded in one technology but one or more components might play an important role in the successful adoption/diffusion/transfer of technologies; hence, barrier analysis for technologies might differ from the generic barriers related to market and economic analysis.

Table 3: Technologies and their Components

Technology	Hardware	Software	Orgware
Solar home system	Solar panels, balance of system components e.g. wiring, switches, mounting systems, etc.	Engineering-based know how for design, installation, operations etc.	Ownership of the system, repair and maintenance, which can be owned by user or energy service companies
Early warning systems for natural disasters	Sensor equipment, telecommunication systems, etc.	The knowledge and expertise required for handling large datasets and control systems, etc.	Institutional set up and decision support system enabling different actors and organisations.
Drip irrigation	Generally available equipment such as plastic tubes, water pumps, etc.	Knowledge of how to design tube systems, how to determine the size of holes and the space between holes, appropriate water pressure, etc.	Organisation to handle access to water, installation and maintenance of the system

Source: Adapted from Boldt, Nygaard, Hansen, & Traerup, 2012

The examples above clearly illustrate how the different components discussed earlier are present in different technologies. An important factor is the varying degree of importance of a certain component in a particular technology. Thus, understanding the nature of technology and the underlying key components is important to identify barriers that could impede smooth diffusion and transfer of technology.

3.1 Generic Barriers

Since 2001, more than 80 developing countries have conducted technology needs assessments (TNAs) with help from the UNFCCC. Table 5 lists the significant barriers to technology transfer for mitigation and adaptation as revealed in recent outcomes of TNAs.¹⁰

Table 4: Barriers in Mitigation and Adaptation Technologies as Reported by Parties in TNAs

Mitigation	Adaptation
Economic and financial	Economic and financial
Technical	Policy, legal and regulatory
Policy, legal and regulatory	Institutional and organisational capacity
Information and awareness	Technical
Market failure/imperfection	Human skills
Human skills	Social, cultural and behavioural
Network failures	Information and awareness
Institutional and organisational capacity	Market failure/imperfection
Social, cultural and behavioural	Network failures

Source: TNA Outcomes: <http://unfccc.int/tclear/tna/outcomes.html> accessed on April 04, 2018

The barriers in the case of both mitigation and adaptation are the same but the list is organised in descending order of the percentage of parties reporting these barriers in these categories. For example, all parties have reported economic and financial, and technical barriers in the case of mitigation technologies while more than 90 per cent of parties reported policy, legal and regulatory along with economic and financial barriers in the adaptation category. Economic, financial and market failure barriers are generally present due to lack of financial resources and developed markets for the technology. International technology investments are hindered by unstable market conditions. In the case of developing countries, an important factor is low income. The adoption of climate mitigation or adaptation technologies as products and services usually involves a higher cost than the use of conventional products and services.

The macroeconomic conditions in recipient countries play an important role in the smooth transfer of technologies. An underdeveloped financial sector, high import duties, high or uncertain inflation or interest rates, uncertain tax and tariff policies, and investment risks are some of the macroeconomic factors that act as barriers to technology transfer.

Financially, firms in developing countries incur high debt costs as they pay significantly higher interest rates as shown in the table below (annual rates for the year 2016). Countries such as Japan, the Republic of Korea (South Korea), the United States and China dominate the space of environmentally sound technologies in terms of number of patents filed (discussed in section 4.2).

¹⁰ UNFCCC – TNA Outcomes: <http://unfccc.int/tclear/tna/outcomes.html> accessed on April 04, 2018

Table 5: Lending Rates in emerging countries and top innovating (environmentally sound technologies) countries for 2016

Country	Lending Rate, per cent per annum
Brazil	52.10
Russian Federation	12.60
South Africa	10.46
India	9.67
China: Mainland	4.35
The United States	3.51
Republic of Korea	3.37
Japan	1.04

Source: <http://data.imf.org> for 2016, accessed on April 15, 2019

Moreover, climate change mitigation projects fail to secure attractive debt terms; the cost of debt is higher as projects have low collateral value, and face competition with mature brown technologies in the same field. These issues are exacerbated by the costly and cumbersome process of technology procurement.¹¹ Section 3.1.1 includes detailed discussion on financial barriers.

Information, legal, regulatory and policy barriers include the absence of policies and regulatory frameworks including codes and standards for the evaluation and implementation of environmentally sound technologies and, more importantly, inadequate understanding of local needs and demands. For instance, the price of energy from conventional sources is low and is often subsidised, which acts as a barrier in the adoption of energy saving measures and renewable energy technologies.

Information failure is caused by limited access to data and knowledge and limited awareness of emerging technologies. The needs of parties at the national or sub-national level might be similar and it is highly likely that the parties might end up duplicating their efforts, wasting time and resources. Another significant barrier is the absorption capacity of receiving countries such as the lack of human and institutional capabilities, insufficient research and development because of lack of investment, inadequate science and educational infrastructure, and institutional corruption.

The current understanding on barriers affecting the transfer and adoption of technologies in developing countries is limited. More research is required to understand the barriers impeding the development, deployment and transfer of technologies in developing countries. TNAs could prove instrumental in arriving at a consensus on barriers that are generic in nature and are common to many developing countries. Additionally, recipient countries must also figure out key barriers specific to their domestic circumstances and the appropriate mechanisms and

¹¹Finance for the International Transfer of Climate Change Mitigation Technologies
https://pub.iges.or.jp/system/files/publication_documents/pub/discussionpaper/4388/TTFinance_final.pdf
accessed on April 08, 2018

reforms needed to expedite the process of development and deployment of state-of-the-art technologies.

Technology transfer frameworks must internalise the local context and circumstances (interests of local communities). For example, two biomass generators established by United Nations Children's Fund (UNICEF) in India in 1979 failed because they used national statistics rather than locally collected data, leading to an overestimation of dung supply (Butera & Farinelli, 1991). Moreover, given the complexity due to the number of stakeholders involved, it is important to focus on the capacity of different institutional actors to adapt technology (orgware). In the next sections, financial barriers and other important barriers in the context of sector, transfer channel and nature of technology have been discussed in detail.

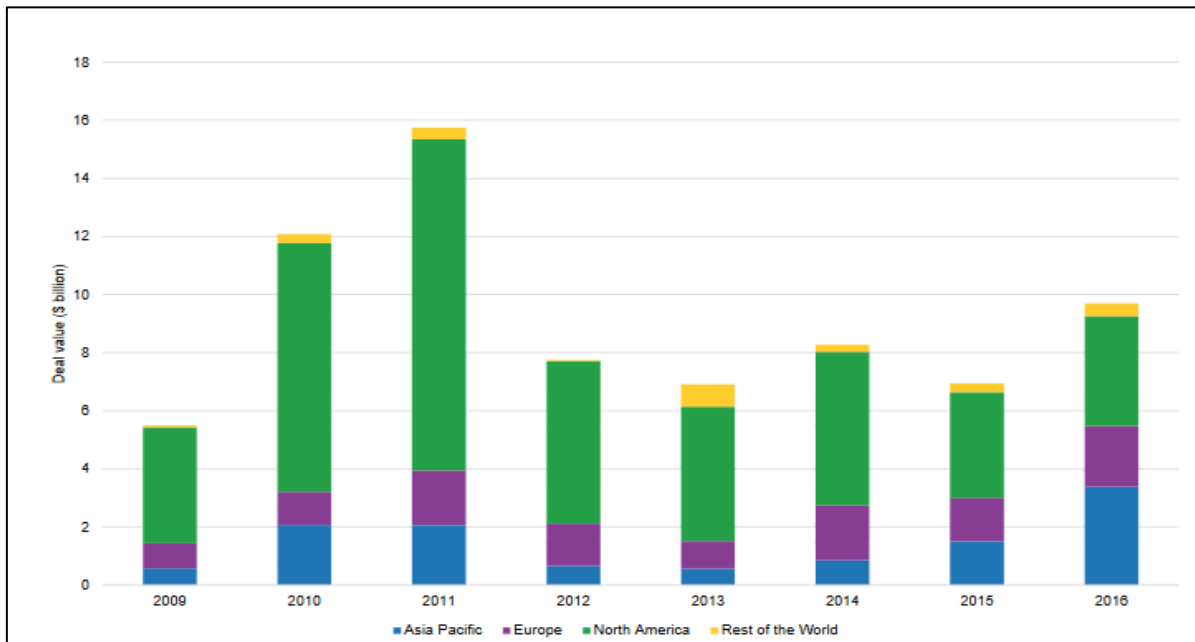
3.1.1 Financial Barriers

Given that financial constraints constitute a major barrier to the development and transfer of environmentally sound technologies, climate finance becomes a crucial element in the effective implementation and eventual success of climate change mitigation and adaptation measures. Despite the global understanding of the need for and the support to ensure adequate financial flows for climate change mitigation measures, actual flows have been limited. Many initiatives have been stalled and sometimes dropped due to lack of financial resources. The higher risk perception associated with the development of new clean technologies and the generally risk averse nature of investors lead to hesitant investor engagement. Lack of information about new technologies makes it difficult for prospective investors to commit funding. Besides, because many of these technologies are new and there is no credit history to benchmark an evaluator's assessments of their viability, investors are reluctant to commit to funding (Goldman, McKenna, & Murphy, 2005). This restricts the deployment of new technologies in new markets, restricting and delaying growth. Further, the lack of low-cost capital and low levels of public investment prove to be additional blocks to the transition of environmentally sound technologies from the research and development stage to commercialisation.

Another issue regarding financing arises in cases that require the adaptation of already developed technology for implementation in a country other than the one in which it was developed. At times, the cost of adaptation and deployment of technology in the recipient country is usually not taken into account when assessing profitability, which leads to losses and deter companies from embarking on new technology development projects.

The decline in venture capital funding from its peak of USD16 billion in 2011 to less than USD10 billion in 2016 has also adversely affected funding for the development of new environmentally sound technologies (see Figure 1).

Figure 1: Global Clean Energy Venture Capital and Private Equity Volumes by Region, 2009-16



Source: (CEP, 2016)

The decline was particularly pronounced in the United States and is believed to have resulted from the adoption of investment models that were unsuitable to the requirements of the clean tech sector. Besides, there has been a shift from investment in early stage financing in the clean tech sector to later stage investments; investments have also tended to flow into relatively less capital-intensive components such as software development and information technology, creating financing gaps within the environmentally sound technology value chain (OECD, 2017). One of the major reasons for the emergence of this pattern is again the risk perceptions attached with the sector.

The up-gradation of existing and development of new environmentally sound technologies require a revival of risk mitigation mechanisms to support the sector, and make it more attractive to investors. Various instruments such as credit enhancements that help in diversifying risks and a blended finance¹² approach to catalyse greater private sector involvement have been used to support the financial requirements of the sector. Given the high-risk perception associated with the sector, the provision of risk guarantees could go a long way to improve its attractiveness to investors. Such guarantees, often provided by development finance institutions (DFIs), help mobilise domestic lending for clean technologies by sharing the credit risk of the project with commercial financial institutions (CFIs). Besides, such guarantees can help lower risk perceptions as banks gain experience in the supervision of clean energy loans and improve their ability to assess project risks more accurately. Drawing on the success stories of financial funds and grants that have supported the clean tech sector, new measures and steps need to be put in place to increase the availability of finance. International

¹² Blended finance is defined as the strategic use of official development assistance for the mobilisation of additional finance towards sustainable development in developing countries.

public finance and grants, backed by strong domestic policies can play a crucial role in not only closing viability gaps and bringing down risks but also in lowering the costs of technologies. Intervention by governments is particularly important in the early stages of development, which could be through enhanced public-private co-operation and through support for research and development of new and innovative environmentally sound technologies. While attracting greater private investment remains a broad-based goal, new and innovative means of meeting financial requirements and risk sharing mechanisms are also needed.

3.2 Intellectual Property Rights

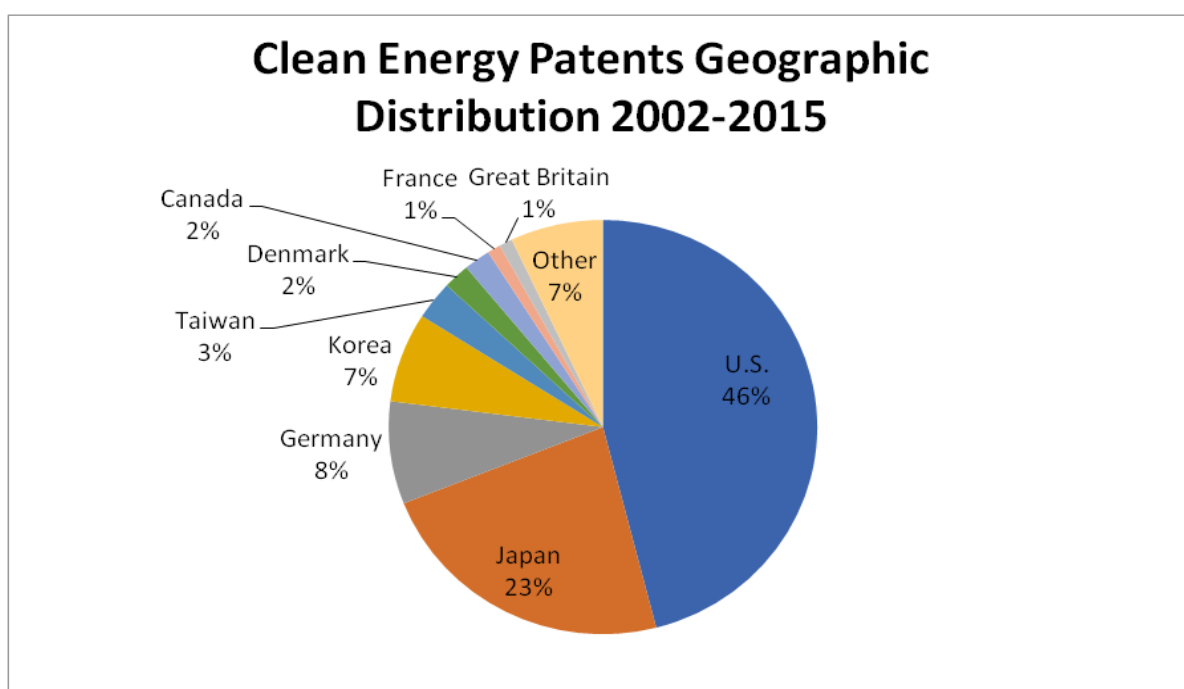
Another major hurdle in diffusing several advanced technologies that could decarbonise the economies of developing countries is the existing IPR (intellectual property rights) regime. IPRs act as an important barrier depending upon whether a certain technology is patented, the availability of viable alternatives, their cost, etc. India's country paper to the Gleneagles Summit (G8 +5) explicitly called for placing some IPRs in the public domain, primarily in the areas of energy efficiency and clean energy.

For convenience, technologies can be placed under three categories (in terms of proprietary rights): unpatented technologies that are in the public domain, patented technologies and future technologies that are likely to come under patents (Khor, 2012).

Technologies that are in the public domain are those whose patents have expired or those that had never been patented. Moreover, governments in developed countries play an important role in funding R&D programmes but in these cases, the technologies developed are not in the public domain or available without any cost. In most countries, governments distribute their patent rights to recipient research institutions; consequently, diffusion of technologies that are publicly funded is subjected to royalties, licence fees, etc., and may not be available for use without restriction (Sathaye, 2005).

Many key technologies are patented and many technologies of the future will be patented. Agenda 21 highlights the issue of technology transfer and patent protection in Chapter 34. In para 34.10, it explicitly states: "*Consideration must be given to the role of patent protection and intellectual property rights along with an examination of their impact on the access to and transfer of environmentally sound technology, in particular to developing countries, as well as to further exploring efficiently the concept of assured access for developing countries to environmentally sound technology in its relation to proprietary rights with a view to developing effective responses to the needs of developing countries in this area*". While patenting protects innovations and enables firms to recover their costs, it may act as a barrier to the transfer of technology to developing countries at an affordable price.

Figure 2: Geographical Distribution of Clean Energy Patents



Source: Rothenberg & P.C., 2016

According to the Clean Energy Patent Growth Index (CEPGI), published quarterly by the Cleantech Group at Heslin Rothenberg Farley & Mesiti P.C., most clean energy patents are privately owned and concentrated in developed countries like the US, Japan, Germany, etc. Hence, the speed of diffusion of the most advanced energy technologies will largely be determined by companies and institutions in the Organisation for Economic Co-operation and Development (OECD) countries (Lee, Iliev, & Preston, 2009).

A strict IPR regime may facilitate better technology transfer through trade, FDI and imports as the interests of innovators will remain protected (Tanaka & Iwaisako, 2014). However, in cases where learning occurs through reverse engineering, such a regime would hinder indigenous development of technology in the early stage of industrialisation (Kim, 2003). In cases where foreign inventors and corporations hold most of the patents, the monopoly right due to patents could suppress local R&D. An important example is that of the production of substitutes to chlorofluorocarbons (CFCs), which was discussed as a success story in Box 1. Firms in India and Korea faced difficulties in obtaining rights to produce CFC substitutes, which hindered their ability to meet their commitments under the Montreal Protocol. In the case of HFC-134a, Indian companies were asked to pay a huge amount (USD25 million) by their US counterparts for the licence and, in some cases, patent owners were not ready to licence the technology to wholly owned Indian companies.¹³ Besides, Indian firms were more vulnerable because the acquisition of CFC technology was relatively recent and they had not recovered the costs before

¹³ Case study 3 India: The issue of technology transfer in the context of the Montreal protocol by Jayashree Watal - http://unctad.org/en/docs/itcdted6_en.pdf Page no.- 45 accessed on May 10, 2018

they had to buy the substitutes. Such cases highlight the challenges posed by IPR regimes in successful technology transfers to developing or least developed countries.

3.3 *Technical Barriers*

Apart from the barriers mentioned in the previous section, there are barriers specific to a sector, the transfer mode and the state of technology. TNAs and biennial update reports establish sector-specific technology needs, prioritising sectors such as energy, agriculture, forestry and other land use, waste, and industrial process and product use based on the emission intensities of these sectors. The nature and maturity of technologies in these cases, along with transaction and assurance cost, varies, presenting certain barriers to successful technology transfer in a particular sector. For example, Indonesia's TNA identifies different sets of barriers (inadequate incentives for R&D, high cost of modelling development, high cost of capital, lack of inter-sector technology transfer and development of policy for peat re-mapping, etc.) for carbon measurement technology, peat re-mapping and water management.¹⁴

Box 4

Technology transfer in biomass-based energy plants in India

The success of technology transfer will depend on ability of technology transfer framework to bring together entrepreneurs from developing countries and technologies from developed countries together. However the success of business (afterwards) will rely on ability to overcome high transaction costs in developing markets.

FOV Biogas, a Swedish clean-tech corporation, has been installing cost effective biomass based energy plants in India through FOV Biogas India, which is based in Chennai. It is a joint venture with the Swedish firm FOV Biogas and Nordic Cleantech, an Indian start-up. It has been operating in different capacities across India with its primary focus on residential waste. The venture is a result of The India Sweden Innovations' Accelerator, a programme backed by The Swedish Energy Agency, Business Sweden and the Confederation of Indian Industry (particularly the CII – Sohrabji Godrej Green Business Centre in Hyderabad). The transfer of technology is facilitated by the import of a fabric-based digester.

Another example is of Orient Green Power Company Limited that is based in Chennai and has been engaged in the business of biomass-based energy plants primarily focusing on agricultural waste. Their efforts along with a Japanese partner, to put up a plant based on chicken litter in Namakkal (near Coimbatore in Tamil Nadu), which has a large poultry industry, failed due to large transaction costs. A similar initiative at setting up a plant for paddy waste with a Chinese partner has been progressing at a slow pace.

¹⁴ TNA – Indonesia:

http://unfccc.int/tclear/misc /StaticFiles/gnwoerk_static/TNR_CRE/e9067c6e3b97459989b2196f12155ad5/621d32b1f9704764be63a9e8004d176e.pdf accessed on April 12, 2018

Energy Sector

The energy sector is the largest emitter of GHGs and the introduction of any new technology will be supply side driven, as end users are less likely to be concerned with the source of power or process of generation than with the availability of reliable power at a reasonable tariff. The energy from conventional sources is reliable and cheap but has a residual impact on the environment. Any new technology, whether solar, wind, or biomass will have to compete with fossil fuel-based power, which is still far more economical than renewable energy. This peculiarity of the sector makes it necessary to provide incentives or subsidies to compensate for the losses of electricity distribution companies. While there is a lucrative market for solar energy (with either direct or indirect government support in the form subsidies in the early stages), cost is a huge hurdle in the case of clean coal technologies and carbon capture and storage technologies. Almost all countries in their biennial update reports and TNAs have prioritised the integrated gasification combined cycle (IGCC) technology to turn coal and other carbon-based fuels directly into pressurised gas – synthesis gas (syngas). While technologies will differ according to the nature of the coal found and used in a particular country and the development of such technologies is fairly indigenous, developing countries face financial constraints in commercialising such technologies. It is important to understand that while renewable energy sources such as solar and wind are driven by market forces, emerging technologies like clean coal technologies must be augmented with technology push policies and programmes as markets are usually inadequate (Herzog, 2017).

As per the outcomes of available TNAs, technologies to convert biomass into energy along with solar photovoltaic technologies are among the highly prioritised technologies; however, the barriers differ for biomass/biogas as the fuel for such plants is not regulated and the fact that different fuel inputs, viz., agriculture waste, municipal solid waste, etc., require different technologies. The unregulated fuel supply makes the role of communities, which are the primary generators and owners of biomass that serves as the input fuel for such plants, very important. The lack of free flow of information about the technologies developed in different countries with similar needs is a major barrier in the case of biomass technologies.

Electric Vehicles and Public Transport Sector

Electric vehicles have been the talk for future mobility, both public and personal. Transportation has emerged as the biggest emitter of GHGs in the end use sector.¹⁵ However, unlike many other technologies, electric mobility is still evolving, presenting an opportunity for north-south research collaboration. The electric mobility patent landscape is dominated by developed countries, as is evident from the table below (Frieske & Klötzke, 2015).

¹⁵ End use sector applications are those applications that are powered by some form of energy, e.g., transport, water heating, space cooling, etc.

Table 6: Leading Institutions in the Field of Electric Vehicles

Rank	Institution	Number of Innovations	Country
1	Toyota Motor	7789	Japan
2	Honda Motor	3073	Japan
3	Nissan Motor	2835	Japan
4	Toyota Jidosha	1987	Japan
5	Hyundai Motor	1255	South Korea
6	Mitsubishi Jidosha Kogyo	1055	Japan
7	GM Global Tech	833	United States
8	Denso	829	Japan
9	Aisin AW	722	Japan
10	Hitachi	685	Japan
11	Robert Bosch	679	Germany
12	Ford Global Tech	655	United States
13	Daimler	637	Germany
14	Kia Motors	427	South Korea
15	Peugeot Citroen Automob	411	France
16	ZF Friedrichshafen	399	Germany
17	Mazda Motor	367	Japan
18	Renault	357	France
19	Toshiba	353	Japan
20	BMW	347	Germany

Source: Frieske & Klötzke, 2015

Emerging markets like India and China are going to drive market demand for EVs in the future. The lack of collaboration among countries and developers will again leave developing countries with a lot of catching up to do in the future. While it is debatable whether intellectual property or patents will act as a barrier, ensuring knowledge spill-over in developing countries by shifting manufacturing, engineering and development of such technologies to recipient countries should be a priority. Research and policy initiatives have been undertaken in developing countries (India, China etc.) and there exists large potential for research collaborations. An important factor in EVs is the asset utilisation rate; with growing urbanisation and population, demand for public transport in India, China and Brazil will provide a lucrative market for EVs.

Energy Efficiency

Energy efficiency initiatives are mostly supply driven and require stringent regulation and enforcement along with financial support. Conserving power is more economical than producing power and thus energy efficiency, especially in low-income countries, is expected to play an important role. Technology transfer in this case could be in terms of consumer goods for household energy efficiency or capital goods for industrial energy efficiency.

India's initiative in household energy efficiency is an excellent model of ensuring rapid diffusion of technology for many low-income countries. UJALA (Unnat Jyoti by Affordable LEDs for All), launched by the Government of India, focuses on promoting and accelerating the adoption of LED bulbs. The scheme allows customers to buy

LED lights for an initial payment of \$0.15 (INR10) each with the balance being paid as part of the consumer's electricity bills in equal monthly instalments of INR10.

But such initiatives require large procurements to reduce per unit cost to compete with prevalent cheaper lighting solutions (incandescent light bulbs). A wider scope exists in the case of large-scale appliances such as heating, ventilation and air conditioning systems, agricultural equipment, etc., but the success of such initiatives would largely depend on low cost per unit of procurement to end users. Apart from high cost of adoption the following barriers could also prevent successful technology transfer in such cases.¹⁶

Box 5

Global Environment Facility (GEF) and Energy Efficiency in India

GEF will be providing financial assistance of USD454 million to Energy Efficiency Services Limited (EESL), a joint venture of public sector units under the Ministry of Power, to scale up energy efficiency programmes and new technology applications. The project aims to support and create enabling conditions for EESL's growth strategy, targeting USD300 million in investments across seven technologies, i.e., street lighting, domestic lighting, ceiling fans, agricultural pumps, super-efficient ceiling fans, tri-generation, and smart grids and meters. Another provision is to set up an Energy Efficiency Revolving Fund (EERF) with an initial corpus of USD13 million from the Asian Development Bank (ADB) as a part of the GEF Trust Fund. EERF will be used to support the three new technologies of super-efficient ceiling fans, tri-generation technologies, and smart grid-applications. The main objective of this fund is to scale up energy efficiency financing and programmes to help cover the initial investment cost of identified energy efficiency projects in India. Another project (GEF-5) focuses on improving energy efficiency in India's MSME sector via continued capacity building, information dissemination, and establishment of standard operating procedures for implementing energy efficiency (EE) investment projects.

¹⁶ UNDP project document – Local development and promotion of LED technologies for advanced general lighting in Vietnam
<http://www.vn.undp.org/content/dam/vietnam/docs/Project%20Documents/PIMS%205193%20VIE%20LED%20CEO%20Approved%20Project%20Document.pdf> accessed on November 20, 2018

- Regulatory barriers: The absence of a regulatory framework to monitor and evaluate energy efficient products and consumer goods in the recipient country
- Institutional barriers: Weak institutional arrangements for testing energy efficiency of products
- Local capacity, knowledge and awareness barriers: Lack of local capacity and knowledge among domestic manufacturers on best practices for manufacturing energy efficient products; lack of awareness among end-users of the costs and benefits of energy efficient products

3.4 Other Barriers

Apart from the barriers listed above, barriers could arise due to the mode of transfer and the nature of the technology (based on its life cycle phase).

Mode of Transfer

Transfer of technology could be in the horizontal or vertical mode. Vertical transfer of technology takes place in terms of relocation or sale of technology products by granting rights of production or licence, or through a simple sale of finished products to the end user in a new location without sharing the intellectual property. Horizontal transfer, on the other hand, is a lengthy process involving long-term sharing of intellectual property, usually via joint ventures or co-operation between a foreign direct investor and a domestic company in the recipient country.

Vertical transfer of technology, in most cases, does not result in knowledge and technology spill-over opportunities. This type of transfer takes place when local firms engage in transnational corporation (TNC) value chains as suppliers. These firms adopt better technologies to meet the specification and quality standards mandated by the TNC. The major barriers are essentially the rules and regulations pertaining to foreign direct investments and ease of doing business in the recipient country.

In the case of horizontal transfers, the technology is transferred primarily in the form of joint ventures, subsidiaries or licensing. Most such initiatives are undertaken by private entities engaging in business. The knowledge spill-over in such cases is higher but it occurs at a very slow pace. Rules and regulations pertaining to intellectual property rights, joint ventures, subsidiaries, etc., impede technology transfer through this mode.

Most international negotiations and mechanisms have focused on horizontal technology transfer, although vertical transfers have been proposed to avoid the risks of high costs and intellectual property right violations. Generally, developing countries have expected facilitation of technology transfers through mechanisms such as government-to-government transfers and increased financial and technology support, primarily through horizontal forms of technology transfer. On the other hand, many developed countries have pointed out the need

for proper incentives to private companies that own the technologies and the protection of intellectual property rights.¹⁷

Nature of Technology

Technology development, in most cases, goes through four stages, viz., the research and development phase, the ascent, the maturity and the decline. In the case of technologies for both climate change mitigation and adaptation, certain technologies can be assumed to have achieved maturity while many others are still in the R&D or the ascent phase. For example, high value photovoltaics have a globally competitive market and foreign imports in this case would threaten the domestic development of these technologies; hence, the need to achieve economic growth might act as a barrier. However, in the case of sectors such as waste management, sustainable infrastructure development, and public transport, etc., national innovation systems in developing countries may not be able to participate in research and development due to the high prospect of failure.

Hence, depending upon the nature of technology, barriers will vary and accordingly, the mechanism for facilitating technology transfer. The four phases of the technology lifecycle are:

- The *research and development* phase, “the bleeding edge” when income from investment is negative and when the prospect of failure is high
- The *ascent* phase when out-of-pocket costs have been recovered and the technology begins to gather strength (sometimes called the "leading edge")
- The *maturity* phase when monetary gains are high and stable
- The *decline* (or decay phase) when the returns from and the utility of the technology decreases.

While developing countries might find it difficult to engage in bleeding edge technologies due to high risk, the diffusion of mature technologies might only happen through the import of consumer goods and capital goods, which could discourage the development of domestic industries and manufacturing capabilities. There have also been cases of technology dumping, which has been defined as transfers to developing countries of older technologies whose environmental performance is lower than that of technologies used in developed countries. There are import regulations that have been adopted by developing countries to curb such practices.

It is also important to understand the nature of technologies according to their market characteristics.

¹⁷ Partnership for Technology Transfer – Tim Forsyth:
http://eprints.lse.ac.uk/4771/1/Partnerships_for_technology_transfer.pdf accessed on March 21, 2018

Table 7: Technology Categories and Market Characteristics

Category	Description	Technology examples
Consumer goods	Goods specifically intended for the mass market; households, businesses and institutions.	Solar home systems, CFLs, energy-efficient air conditioners, drip irrigation tubes, seeds for drought resistant crops.
Capital goods	Machinery and equipment used to produce, for instance, consumer goods or electricity.	Utility technologies, such as biomass plants, small-scale hydropower plants, or technological parts thereof; could also be machinery used in agriculture, and technologies used in industrial processes
Publicly provided goods	Technologies in this category are often (although not always) publicly owned, and production of goods and services are available (free or paid) to the public or to a large group of persons.	Sea dykes, infrastructure (roads and bridges, sewage systems), mass transport systems (metros).
Other non-market goods	Non-tradable technologies transferred and diffused under non-market conditions, whether by governments, public or non-profit institutions, international donors or NGOs.	Early warning systems for drought, seasonal forecast of rain for optimal planting, seed banks, etc.

Source: Boldt, Nygaard, Hansen, & Traerup, 2012

The barriers in each of these cases would differ depending on the ownership and nature of the technologies. For example, in the case of publicly owned technologies, negotiations are likely to be bilateral between governments. The success and failure of such technologies will depend upon the customisation of technologies to suit local needs and the absorption capacity of the recipient country. In the case of consumer goods and capital goods, negotiations will be more trade related and the major barrier will be transactional costs related to foreign investment in the recipient country.

Overall, the success of technology transfer will rely heavily on an understanding of the nature of technology, the life cycle of the technology and the stakeholders involved along with the mode of transfer. In next section, trends in technology development have been discussed by taking patents as a measure of technology development to identify dominant sectors. The analysis, carried out based on the OECD patent database, looks at technology development in G20 countries.

4 Prioritised Technologies – Analysis of G20 Countries

The G20 forum brings together the major economies of the world. The group produces 73.54 per cent of global GDP and is responsible for 81 per cent of all global CO₂ emissions. All major innovating countries (US, South Korea, Japan, Germany, China, etc.) are members of the G20 and together dominate the space for environmentally sound technologies. Sections 4.1 and 4.2 discuss prioritisation of technologies among G20 countries and technological development to understand current trends.

4.1 *Prioritised Technologies among G20*

Among the technologies that have attracted the greatest focus in developed countries is that related to renewable energy. In October 2015, under the Turkish presidency, G20 countries adopted the “Toolkit of Voluntary Options for Renewable Energy Deployment”. The International Renewable Energy Agency (IRENA) has been engaged in co-ordinating the toolkit activity. Under the Chinese presidency in 2016, IRENA presented G20 countries with an in-depth REmap study.¹⁸

The REmap study analyses the current situation and the renewable energy potential in G20 countries and suggests policy options for rapid development of renewable energy capacity.

One of the most critical areas identified by the REmap is biomass energy. In 2030, according to projections that assume rapid renewable capacity build up, almost half of the renewable energy will be sourced from biomass. Current policies, however, do not focus on developing technology related to bio-energy. Many developing countries in the G20 have tremendous bio-energy potential. Biomass is used to produce bio-fuels, which feeds into the transport sector – an area that is the least penetrated by renewable energy currently.

Another area that the REmap recognises as underutilised is the deployment of more renewables in end-use sector applications. The G20 has done significant work in the field of energy efficiency (EE). An added thrust in the end-use sector is needed in the form of electrification. Electrification, coupled with the greening of the grid, will help renewable energy sources penetrate all sectors of the economy. Electrification in the area of transport via electric vehicles and the use of electricity to power public transport will reduce the use of fossil fuels. This will not only reduce greenhouse gas emissions but also reduce local pollution significantly. Considering the deteriorating air quality levels in cities across the world, pushing for electrification of transport has become extremely important. When one considers the underappreciated potential of RE in the end-use sector, technologies related to solar water heating and solar district heating also come up.

4.2 *Environment Related Technologies and G20 Countries*

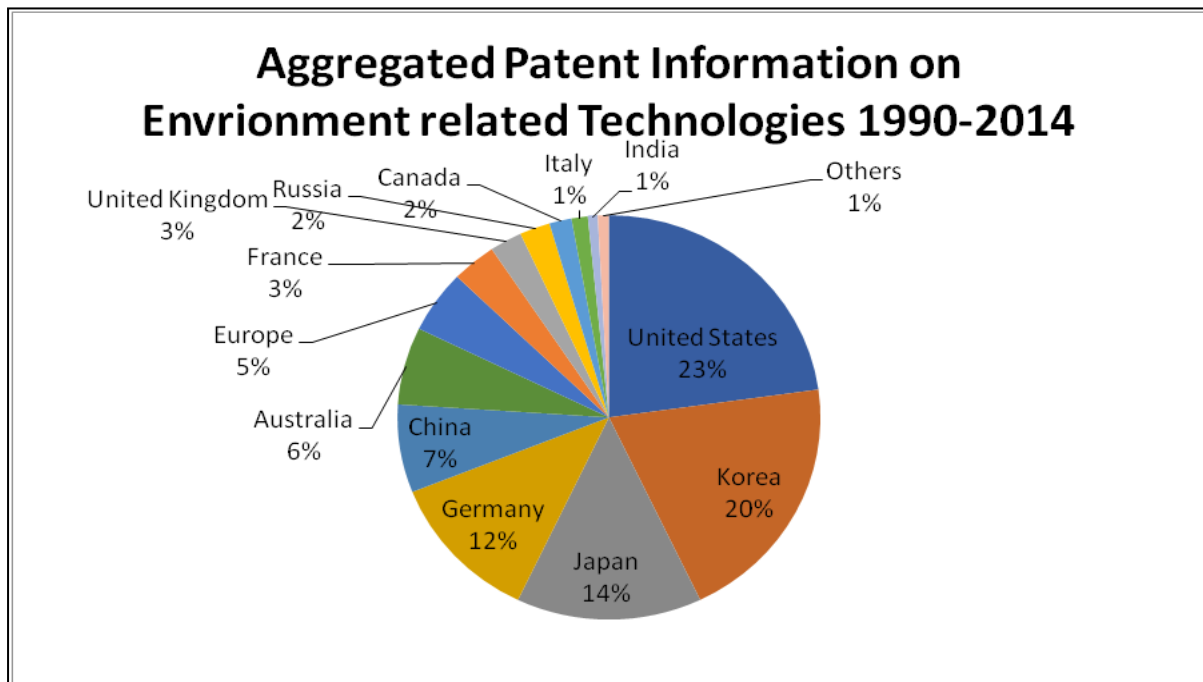
Based on the OECD patent database¹⁹ for patents from G20 countries, excluding countries collectively represented by the European Union in the G20, this section focuses on understanding the distribution of environment related technologies and identifies emerging technologies. Most patents related to environment technologies have been registered in the United States, which tops the chart with 23 per cent, followed by Korea (20 per cent) and Japan (14 per cent). There is a clear divide among developed and developing countries in terms of

¹⁸ IRENA G20 Toolkit: <http://www.irena.org/publications/2016/Jun/G20-Toolkit-for-Renewable-Energy-Deployment-Country-Options-for-sustainable-growth-based-on-Remap> accessed on June 15, 2018

¹⁹ OECD Patent Database: https://stats.oecd.org/Index.aspx?DataSetCode=PATS_IPC accessed on August 13, 2018

the number of patents filed in the field of environmentally sound technologies with China being a notable exception. The divide highlights the lack of capacities in developing countries to innovate and the need for technology transfer from developed countries to developing countries.

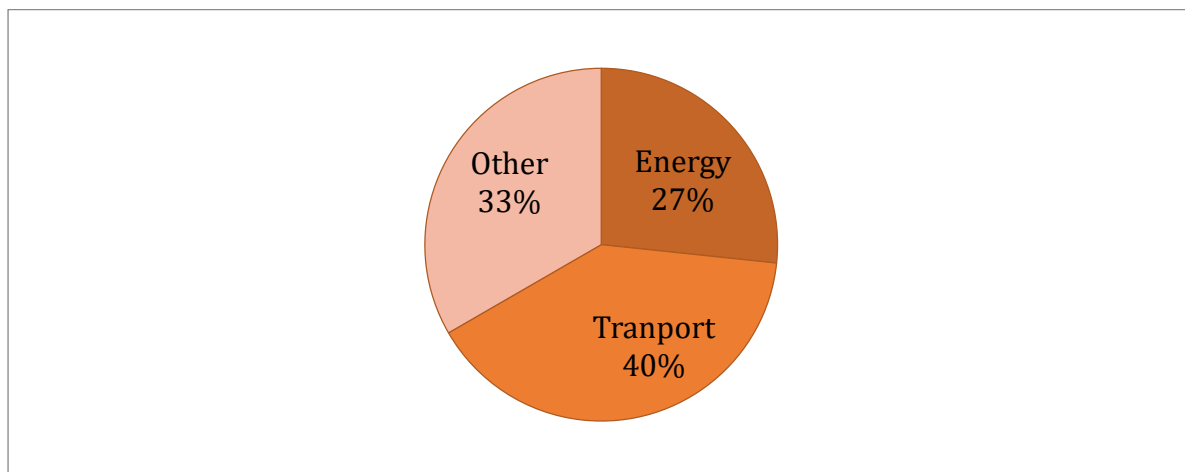
Figure 3: G20 Countries Environment Related Technologies - OECD Patent database



Source: Author's calculations based on data from OECD patent database

Another important aspect is the sectors in which these patents have been filed. The transport sector has the maximum number of patents followed by energy and a few other technologies. These other technologies include ICT (Information and Communication Technologies) for energy efficiency in buildings, carbon capture and storage, water and wastewater treatment, and climate change mitigation technologies in the production process for final industrial or consumer products. Both the transport and energy sectors are set to grow exponentially in developing countries like India, Brazil, China, etc., and firms which own these patents will benefit from these emerging markets. Unlike developed countries, which have relied on fossil fuels to achieve growth, developing countries face constraints due to climate change commitments. Thus, it is necessary to ensure the economic development of developing countries by making sure that they benefit from industry localisation effects of environmentally sound technologies. It will require strong innovation systems and capacities in recipient countries to ensure successful diffusion of matured technologies and the development of new technologies in sectors (agriculture, water, infrastructure, forest, soil, etc) that may be ignored by developed countries.

Figure 4: Related Technologies - Dominant Sectors



Source: Authors' calculations based on data from OECD patent database

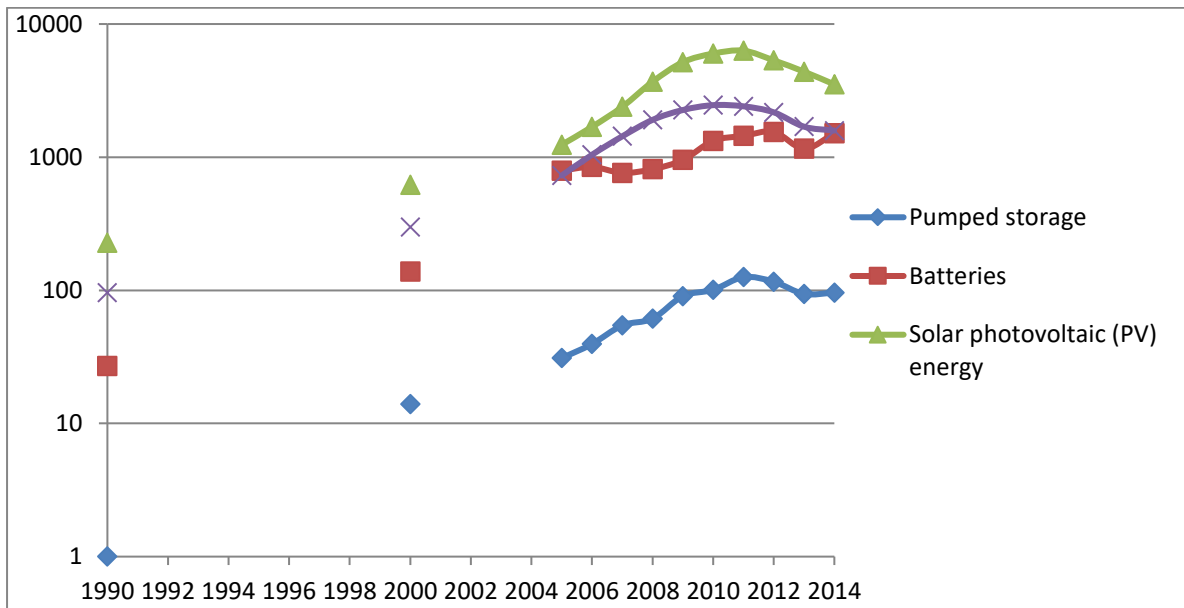
In the next few sections, trends in technology development in the sectors mentioned above have been discussed. These technologies have been selected based on the absolute number of patents filed and the rate of growth in the number of patents in recent years. In the charts shown below, the vertical axis shows the log value of the total number of patents filed in a particular category to improve the representation of some new technologies where the absolute numbers of patents are few, but annual growth rates are high.²⁰

Energy:

In the energy sector, solar photovoltaic has been the top technology in terms of the absolute numbers of patents, followed by wind energy technology. There has been an increasing trend (number of patents and the rate of growth) in batteries and pumped storage. Energy storage technologies are critical in the case of renewable energy to ensure their seamless integration into the grid without jeopardising grid stability. As countries around world expand their renewable energy portfolio, RE integration remains a challenge for all countries. The pattern of patents filed in solar photovoltaic energy and wind energy suggests stability in the development and commercialisation of these technologies, indicating trade as the appropriate channel of technology transfer. However, there exists potential for collaborative research and development in storage where the trend of patents indicates an increasing interest in these technologies.

²⁰ Data from the OECD patent database was available for the year 1990, 2000 and from 2005 to 2014; hence, there is a break in the chart.

Figure 5: Top Technologies - Energy Sector

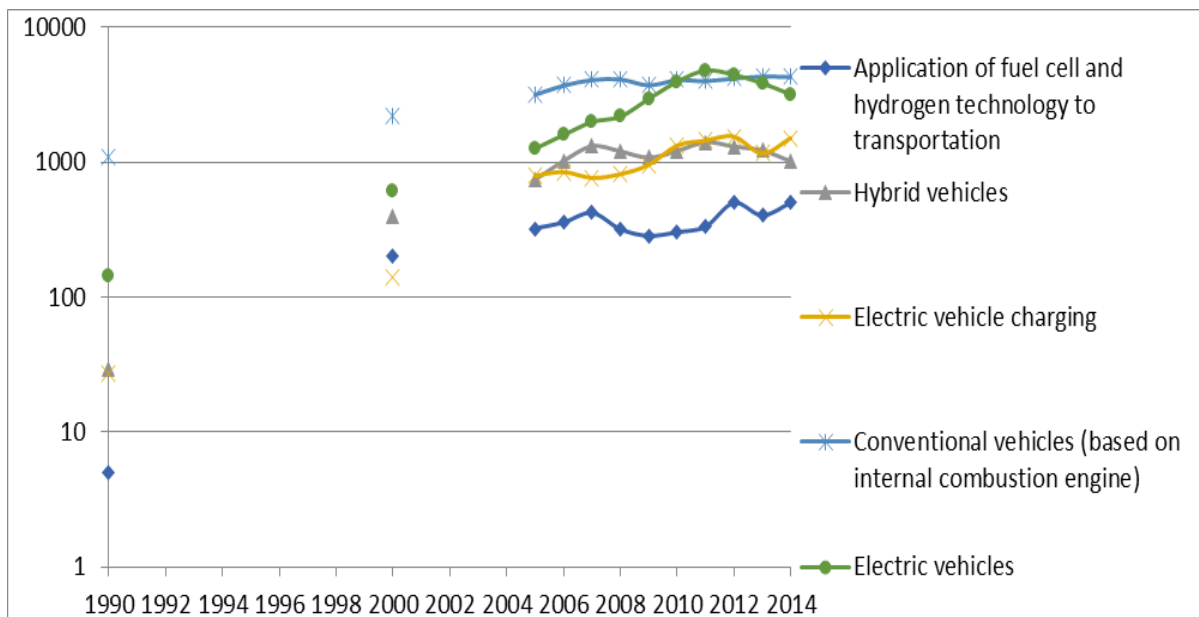


Source: Authors' calculations based on data from OECD patent database

Transport:

There has been constant innovation to improve the environmental performance of conventional vehicles along with interest in new technologies such as the application of fuel cell and hydrogen technology to transportation, electric vehicles and charging infrastructure for electric vehicles. In addition to innovations directly related to electric vehicles, innovations for supporting infrastructure are also becoming crucial.

Figure 6: Top Technologies - Transport Sector

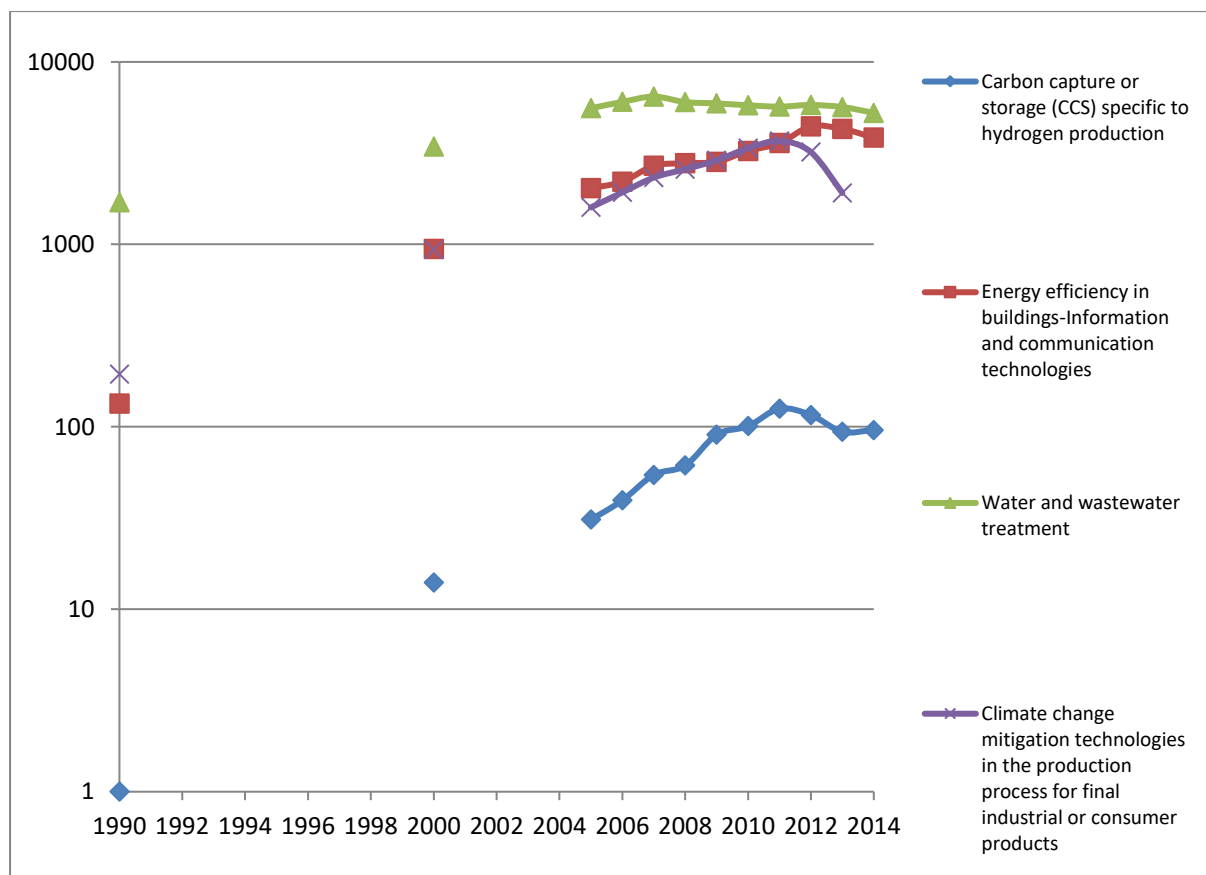


Source: Authors' calculations based on data from OECD patent database

Others:

Miscellaneous technologies such as carbon capture and storage, energy efficiency in buildings, water and wastewater treatment, and climate change mitigation technologies in consumer products have also registered growth in terms of the number of patents filed. While the number of patents filed remains small for carbon capture and storage (CCS), the trend has been promising. CCS, in recent times, has gained prominence as a method to remove carbon from the atmosphere. There is growing interest in similar technologies that can be used in coal-based thermal power plants, which is highly desirable by countries looking for cheap but clean power. Several patents have been filed in waste and wastewater treatment technologies, signifying the current plight of environment in urban areas. There has also been an increasing trend in patents in ICT for energy efficiency in buildings, an area where India has performed poorly.

Figure 7: Other Technologies



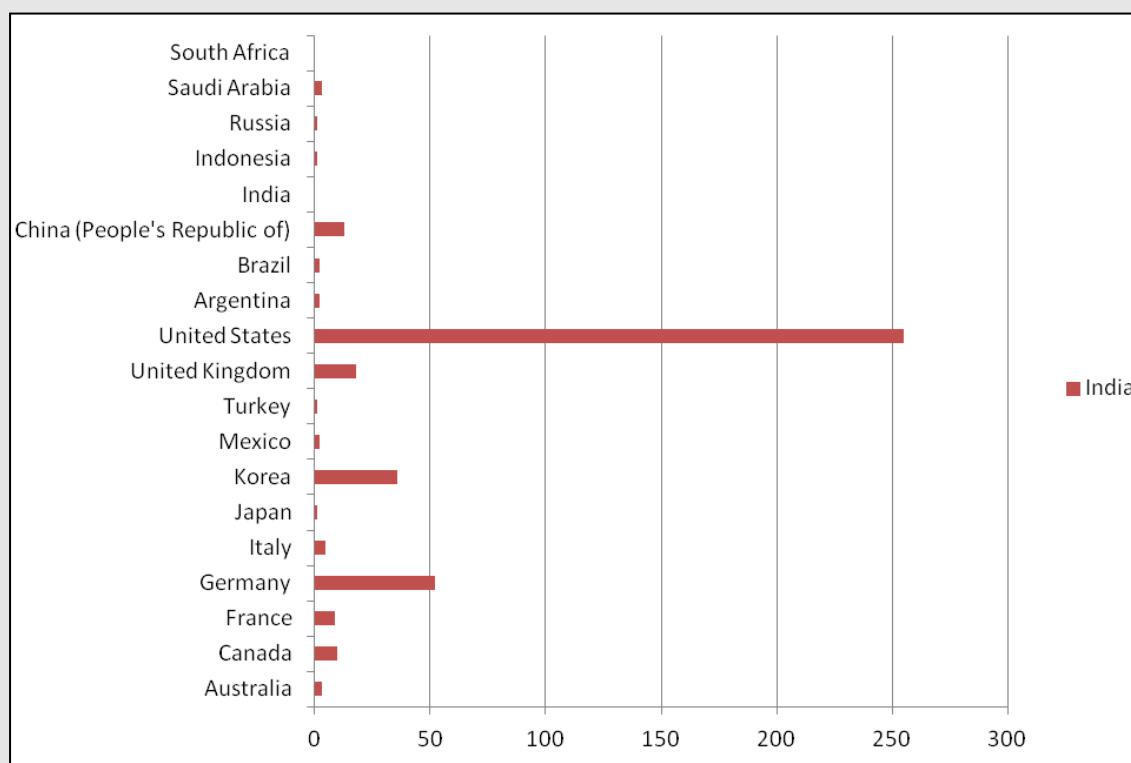
Source: Authors' calculations based on data from OECD patent database

Box 6

Bilateral Co-operation between India and other G20 Countries

Among the G20 countries, the maximum number of patents that has been filed by Indian scientists has been in partnership with their US counterparts. Co-operation among countries here has been defined by the country of residence of collaborators on a patent.

Figure 8: Bilateral Co-operation – India and Other G20 Countries



Source: Author's calculations based on data from OECD patent database

5 Existing Frameworks and Way Forward

Most existing international frameworks have tried to address the needs and concerns of both developing and developed countries while addressing issues in technology transfer and development. In general, negotiations have tended to revolve around arguments regarding the responsibility of developed countries toward developing countries. But it is also crucial to measure and manage technology transfer to better understand its intended impact and contribution toward climate change actions. Financial flows, which are generally reported by developed countries, are prone to greenwashing.^{21 22}

²¹ Discussion paper by Department of Economic Affairs, Ministry of Finance, Government of India- Climate Change Finance, Analysis of a Recent OECD Report: Some Credible Facts Needed: http://dea.gov.in/sites/default/files/ClimateChangeOEFDReport_0.pdf accessed on April 24, 2018

²² Technology Transfer Measurement and Greenwashing: Technology transfers are usually reported in terms of the value of the FDI inflow into a particular economy, the volume of imports, the value of the acquired

5.1 Existing Frameworks

5.1.1 Global Technology Sharing Framework

Under the UNFCCC, the technology mechanism (TM) was established in COP 16 (2010). The TM comprised two arms, viz., Technology Executive Committee (TEC), and the Climate Technology Centre and Network (CTCN). The TEC was the policy arm of the TM whereas CTCN was the implementation arm. COP 17 agreed on the arrangements necessary to bring CTCN online by 2012 and it was decided that an independent review would be undertaken periodically. Accordingly, the first independent review was scheduled in 2016.

The report of the independent review, which was released in August 2017, revealed interesting insights about the functioning of the technology transfer platform at the international level (United Nations Framework Convention on Climate Change, 2017).

CTCN had done great work in the initial years of empowering nationally designated entities (NDEs). They undertook many training programmes for officers at NDEs to create awareness on the opportunities and possibilities of collaboration with the CTCN for domestic projects. The CTCN and NDEs have not been very successful in transferring the knowledge of these opportunities to interested parties, partly due to lack of sufficient resources. CTCN is still a small organisation with a huge mandate of service to all countries that are part of the UNFCCC. CTCN has also built a complete knowledge management system (KMS) to document all the work that it has done in various projects across the world. The review found that despite investing heavily in building the KMS, it was not used as widely as was hoped for. Thus, on the recommendation of the Advisory Board, funding for KMS was slashed, halting further development.

Figure 9: CTCN Projects



Source: <https://www.ctc-n.org/>, accessed on March 27, 2018

intellectual property, etc. Greenwashing is the practice of making an unsubstantiated or misleading claim about the environmental benefits of a product, service, technology or company practice (climate finance in this case).

CTCN aims to achieve the convergence of financial resources and technical expertise. It has managed to utilise the Global Environment Fund (GEF) to implement projects of technical assistance. Another important observation in the review is the lack of sustained funding from the GEF to CTCN because of an ad-hoc, project-based approach that has resulted in limited financial resources. The report states reasonably that it is too early to state the effectiveness of the projects undertaken by the CTCN so far. The long-term benefits will be revealed after some years. It is thus difficult to assess the impact of the funding. This has led to some concerns about evaluation and transparency. It has been difficult for the organisation to show value for money. Technology transfer, be it vertical or horizontal, is a bottom up activity whereas the CTCN's approach is largely top-down. In this model, the role of developed countries is limited to being donors of funds. A business-oriented platform that will motivate firms in developed countries to participate actively as well as alleviate the funding problem is needed. Section 5.2 provides details on how this can be done.

Table 8: Outcome Indicators – Targets and Achievements

Outcome Indicators	Targets for the fifth year of implementation (2017)	Achievements as at the end of 2016
Climate technology investments deriving from CTCN assistance and post-response plan intervention funding, directly or indirectly attributable to CTCN activities	USD0.6 billion	USD5 000 committed USD1.14 million under direct negotiation or submitted to investors or donors USD350 million estimated investment potential
Number of national and sectoral technology plans resulting from CTCN assistance	50-75	7
Number of new country-driven technology projects and/or strategies (policies and laws) designed, implemented and scaled up as a result of CTCN assistance	100	9
Number of public-private partnerships formed as result of workshops	13	3
Number of twinning arrangements as a result of networking events	18	4
CTCN activity that directly or indirectly created a South-South, North-South or triangular collaboration	No target	5

Source: United Nations Framework Convention on Climate Change, 2017

5.2 *Way Forward*

The success of a technology transfer framework will depend on its ability to address the peculiar nature of different technologies, build absorption capacities and the availability of financial resources.

5.2.1 *Separate Technology Verticals*

In Section 2.2.1, it was pointed out that different types of policies are required to support different types of technologies. These differences are related to the inherent characteristics of different technologies. Additionally, different technologies are at different stages of development at present and require different business models. A technology-sharing platform must treat every technology distinctly based on the differences mentioned above. Thus, creating separate verticals for technologies will be the ideal way to proceed. This will be useful to accommodate already undertaken initiatives in the technology transfer mechanism without significant modifications.

5.2.2 *Matching Sub-national Contexts and Capacity Building at Local Levels*

The technology needs at the sub-regional level in different countries may not be the same because of geographic, demographic or other reasons. South Africa had requested CTCN (UNFCC Technical Mechanism) for research help in sub-national level technology needs assessment (TNA).²³ Another example is of adaptation measures for coastal cities. Indonesia had submitted an application to CTCN for flood management technology for the city of Jakarta.²⁴ Coastal cities in other countries require similar technologies as well. Matching sub-national needs across borders will not only enable sharing of viable solutions that some developing countries might already possess but also help reap the benefits of technology from developed nations. Owners of relevant technologies will also benefit from such an effort, as they will cater to a larger collective demand from various countries. This policy recommendation follows the precedent set in cases where smaller countries have come together to request technologies; for example smaller African countries submitted group requests to CTCN with great success.²⁵

²³ CTCN - The Development of Technology Needs Assessment at Sub-national Level:
<https://www.ctc-n.org/technical-assistance/projects/development-technology-needs-assessment-subnational-level> accessed on May 18, 2018

²⁴ CTCN – Hydrodynamic modelling:
<https://www.ctc-n.org/technical-assistance/projects/hydrodynamic-modelling-flood-reduction-and-climate-resilient> accessed on May 21, 2018

²⁵ CTCN- West Africa:
<https://www.ctc-n.org/technical-assistance/projects/mainstreaming-gender-climate-resilient-energy-system-west-africa> accessed on May 25, 2018

5.2.3 Financial Synergies

As discussed in section 3.1.1, financial barriers are significant in the development, transfer and diffusion of environmentally sound technologies. CTCN has been unable to mobilise the expected level of financial resources. And risk mitigation remains the biggest challenge. International forums such as the G20 can mobilise commercial funds coupled with GEF funds to implement projects. That will also reduce the cost of lending, which is another barrier to technology transfers.

Initial support and adequate financing can deal with a majority of financial barriers and assist in scaling up the clean technology sector. It will also help boost investor confidence. The impact of various climate and green finance funds that have been set up at the international as well as national level testify to the positive effects that initial support and adequate funding can have on the adoption of clean technology. For instance, the Clean Technology Fund (CTF), which is a USD5.5-billion fund of the Climate Investment Funds (CIF), has been mobilising resources in developing countries to enable smooth transition to low carbon technologies. The idea is to bring down technology costs as well as attract greater finance for the overall development of the clean technology sector. Funds from the CTF, supplemented by funding from multilateral development banks (MDBs), have helped the successful adoption of clean technologies. In Morocco, CTF co-financed a concentrated solar power (CSP) complex with the World Bank and African Development Bank (AfDB) that reduced the dependence on government subsidy. A few other similar examples have been listed below.

- In Thailand, CTF with ADB and IFC (International Finance Corporation) supported some projects in the field of renewable energy, leading to better channelization of additional funding from local banks. Financial support in the early stage of technology development can attract a higher amount of finance.
- The setting up of wind energy farms in South Africa with the help of the CTF in collaboration with MDBs not only helped to reduce the gap in financing but also to increase incentives for further investment.
- In Turkey, various MDBs and financial intermediaries utilised funds from the CTF to address market barriers and accelerate investment in renewable energy and energy efficiency in the country. This activity had a strong positive impact, particularly on the energy efficiency market, which scaled up to a size large enough to attract finance on a purely commercial basis (Climate Investment Funds, 2017). Thus, energy efficiency financing helps create markets for ‘risky’ technologies.

6 Conclusion

Developing countries have held the view that the Paris Agreement should continue to be guided by the principles of the UNFCCC, especially the principle of CBDR (common but differentiated responsibilities). In recent times, developing countries like India have insisted that all climate actions must stem from climate justice. Adhering to these principles, India has called for more collaborative global action on technology transfer. There ought to be

collaboration between countries for transfer and development of technology so that environmentally sound technologies are not exorbitantly expensive for developing countries. The constant focus of international negotiations (in the G20 and UNFCCC) on technology development and transfer testifies to the importance of the issue. However, the complexities in the nature of technology, channels of technology transfer and involvement of multiple stakeholders have made it difficult for countries to arrive at a consensus on the appropriate technology transfer framework despite its benefits to both developing and developed countries. Lack of sustained financial support from developed countries and international organisations to developing countries is a major concern.

Lack of finance has emerged as the biggest barrier to the transfer of technology, whether mitigation or adaptation. There is need to mobilise greater financing for environmentally sound technologies not just for related R&D but also for the early stages of commercialisation and for sharing risks. For example, India has set up the Partial Risk Guarantee Fund (PGRF) for energy efficiency. It is a risk sharing mechanism that lowers the risk for the lender by providing a guarantee for at least a part of the loans advanced. It caters to the need to balance the high risk perception associated with the sector, guaranteeing a maximum 50 per cent of the loan (only principal).

Macroeconomic conditions (high lending interest rates), absence of regulatory (or policy) framework, limited access to information on technologies, etc., have also been reported by the parties as key barriers impeding the transfer of technology. Another important issue is intellectual property/patent rights. While strong enforcement of the IPR framework in the recipient country is desirable as patents of technology received will be protected by it, a strict framework in countries where such technologies are developed makes it difficult for firms in recipient countries to obtain patent rights as is evident from the case of CFC alternatives. In the case of emerging technologies, it is desirable to promote collaborative research that could result in joint ownership of patents. For example, technologies in the case of electric vehicles are usually protected heavily by IPR regimes and can be expensive to buy for developing and underdeveloped countries. Barriers could also arise due to the nature of the technology (stage of development), modes of transfer and sector-specific challenges.

Current frameworks to facilitate technology transfer have not been able to achieve desired results and overcome barriers. The independent review of CTCN shows the disappointing performance of the centre, notably in securing finances for technology transfer. The ad-hoc, project based approach has resulted in the limited availability of resources and consequently, the CTCN has not been able to meet several of its targets as per the review. A different approach focusing on achieving greater financial synergies between different funding agencies and attention to the nature of technologies and sectors could help technology transfer frameworks in achieving their targets.

As far as technologies are concerned, most of the innovations are taking place in transport and energy sector. There has also been growth in the number of patents for other technologies such as waste water treatment, ICT for energy efficiency in buildings, carbon capture and storage,

etc. Since most of these innovations have taken place in developed countries, these address the problems faced by these countries. For example, adaptation technologies, technologies in natural resource management, agriculture, etc., which are more relevant for developing countries, have not aroused much interest. Developing and underdeveloped countries must assess their technology needs and build domestic capacities to innovate in sectors that may be ignored by developed countries.

In the case of India, TIFAC came out with TIFAC Vision 2035, which lists the technology needs of the country. India has been working towards achieving greater energy efficiency and renewable energy penetration. The overall performance of the country has been promising in the sector, except in the case of energy efficient buildings. In the case of renewable energy, India has aggressively been working on increasing the share of solar, wind and hydropower in electricity generation and has focused, at the same time, on cleaning its thermal power plants. India has brought together countries across the globe possessing significant solar energy potential under the umbrella of the International Solar Alliance (ISA). ISA is attempting to promote collaboration on solar technologies and to test and establish best practices in business models and policies in the sector.

While there has been rapid technological advancement in the energy sector, adaptation technologies for enhancing resiliency in agriculture and natural resource management are yet to pick up. Climate change undoubtedly is going to have an adverse impact on agriculture. The negative impact on yields in Sub-Saharan countries and South Asian countries due to the frequent occurrence of floods and droughts, irregular precipitation, depleting water levels and poor soil management poses a threat to food security in the Sub-Saharan region and in South Asian countries. The involvement of large economies like India, China and Brazil is important to address the issue of improved varieties of seeds and the development and transfer of agricultural technologies for water management, efficient irrigation and drought/flood resistant variety of seeds. Developing countries need to match their sub-national contexts to scale up developments in these sectors.

Overall, there are no contrary views on the importance of technology transfer to combat climate change but lack of finances, understanding of technologies, collaborative research and development and understanding of circumstances in recipient countries, and the issue of intellectual property rights and ad-hoc project based approach in financing have impeded technology transfer to developing countries. Technology transfer will assist both developing and developed countries in achieving their climate change commitments and economic development but recipient countries will have to build strong innovation capacities to obtain maximum benefits from the technologies received. A technology transfer platform that strengthens national systems of innovation and initiatives such as an experts'/scientists' network to collaborate on climate related technology development will help developing countries to catch up with developed countries.



Appendix

Current Technology Needs Assessment in India and its RE Capacity

In 2015, the Technology Information, Forecasting and Assessment Council (TIFAC), an autonomous organisation under the Department of Science and Technology, Government of India, undertook a comprehensive scenario building exercise to come out with ‘Technology Vision 2035’ for the country. TIFAC has categorised various technologies in four categories, viz., those that ‘are readily deployable’, ‘needs to be moved from lab to field’, ‘require targeted research’, and ‘are still in the imagination’. Of these four, the second and the third categories are relevant in relation to the discussion on international technology transfer. The following table provides a list some of the technologies across different sectors that are classified in the 2nd and 3rd categories in ‘Technology Vision 2035’.

Table 9: TIFAC Vision 2035 – Important Technologies

Technologies		
Advanced Clean Coal Technologies	●	●
Alternate Fuel Based Transportation	●	●
Real Time Dense Spatial Air Quality Monitoring	●	●
Climate Smart Agriculture	●	●
Solar PV	●	
Nuclear Fusion		●
Fusion Fission Hybrid Reactor		●
Advanced Coal Cycles		●
Shale Gas	●	
Bio-refineries		●
Hybrid Storage	●	
Fuel Cell	●	●
DC Grids	●	
Wireless Power Transmission		●
Green and Net Zero Energy Buildings	●	●
Heat Recovery Systems	●	●
Novel Modes of Transport		●
Energy Efficient Electrical Equipment	●	●
Accurate Weather Forecast at the Micro Level	●	●
Using Indigenous Knowledge for Ecosystem Protection	●	

Note:  - “needs to be moved from lab to field”  - “requires targeted research”

Source: Technology Information, Forecasting and Assessment Council, 2015

As per capita income increases, energy consumption will increase, and India will face a significant increase in the demand for energy. India, with other developing countries, has the more difficult task of increasing energy access, increasing the share of renewable energy and reducing GHG emissions simultaneously. The following are some of the efforts made by the Indian government to address the challenge:

- **Energy Efficiency:** Energy efficiency labelling programmes under the Bureau of Energy Efficiency (BEE) are intended to reduce energy consumption without diminishing utility. Efficiency standards are progressive and become more stringent over time, driving out inefficient appliances from the market. The government has developed the Energy Conservation Building Code (ECBC) to promote energy efficient buildings. However, technological capacity in this sector is limited. Under the National Mission for Enhanced Energy Efficiency (NMEEE) implemented by the central government, there are four targeted initiatives designed to enhance energy efficiency in energy intensive industries:
 - Perform, Achieve and Trade (PAT)
 - Energy Efficiency Financing Platform (EEFP)
 - Market Transformation for Energy Efficiency (MTEE)
 - Framework for Energy Efficient Economic Development (FEEED)

According to the latest energy efficiency global rankings, India ranks 15th; it is the second best performing country among emerging economies in G20 in advancing energy efficiency (American Council for an Energy-Efficient Economy, 2018). India has done exceedingly well in the transportation sector, earning second rank in the sector wise ranking. Currently, Bharat Stage (BS) IV (Euro 4 equivalent) emission standards are applied throughout the country. The government has demonstrated its commitment to implementing stricter standards over time. For example, it has been planned to roll out Bharat Stage – VI norms directly leapfrogging BS V norms to curb air pollution and reduce emissions. Recently, the government modified the design of the (to be built) Barmer Refinery, owned by HPCL (a state-owned company), to upgrade it to Bharat Stage VI (equivalent to Euro 6) emission standards.

As mentioned earlier, due to limited technological capacity in energy efficient buildings, India has performed poorly in that sector, ranking 21st (lowest sector wise rank among all sectors). Providing affordable housing as a developmental priority has overshadowed efforts to ensure greater energy efficiency of buildings. India can benefit from technology trade in this sector, supported by the financial investment necessary to make these technologies economical. Industrial efficiency remains a big challenge in India. Other developing countries like Mexico and Indonesia have performed better than India in this sector.

- **Renewable Energy:** The Indian government has set an ambitious target of installing 175 GW of cumulative renewable energy capacity by 2022. This target is sought to be achieved by establishing dedicated solar parks and incentivising rooftop solar power. The government has sanctioned the development of new solar park infrastructure – 47 solar parks of aggregate capacity 26,694 MW has been approved in 21 states up to November, 2018 (PIB, 2018). Solar capacity of 8.9 GW has already been allocated across eight solar parks in the country.²⁶ The manufacturing capacity of solar panels is extremely limited with very few indigenous suppliers. Many new solar cell chemistries

²⁶ Bridge to India – India Solar Handbook 2017, available at https://www.bridgetoindia.com/wp-content/uploads/2017/05/BRIDGE-TO-INDIA_India-Solar-Handbook_2017-1.pdf accessed on June 17, 2018

are being tested in the labs but have not found investors who are willing to commercialise the technology.

- **Cleaner Thermal Power:** The Energy Conservation (Amendment) Act, 2010, promotes efficient use of energy and its conservation. All new thermal power plants will be based on supercritical technology. Various clean coal technologies are being tried in India to increase the efficiency of power generation and to reduce emissions. These technologies are being developed indigenously. In recent years, due to various reasons, funding for R&D in this area has shrunk. Considering India's dependence on cheap domestic coal and the increasing demand for electricity, a renewed thrust on R&D is required. In 2017, the National Centre for Combustion Research and Development (NCCRD) was established in co-operation with two national institutes of excellence – the Indian Institute of Technology, Madras, and the Indian Institute of Sciences, Bangalore. Beyond fundamental research, the NCCRD works on applied fields such as aerospace propulsion, automotive combustion, fire suppression, and thermal power. Universities from Germany, China, and Australia are among the academic collaborators of the NCCRD. The centre has partnered with leading companies from India and abroad. Such collaboration is an ideal conduit for sustainable technology transfer and needs to be promoted more strongly.
- **Hydropower:** There are twelve major river systems in the country with a total catchment area of 252.8 million hectares. Hydropower projects in India mostly consist of big dams, which have a difficult project development trajectory due to their large economic and environmental footprint. The Indian government has vested in the Ministry of New and Renewable Energy the responsibility for developing small hydropower (SHP) projects with capacity up to 25MW. The estimated potential from such projects in India is around 20 GW. The cumulative capacity of SHP projects in India was about 4.5 GW (PIB, 2018). MNRE provides central financial assistance to the Alternate Hydro Energy Centre of IIT Roorkee for its technical support to the SHP sector. The centre has undertaken research activities to advance SHP technology and has conducted training programmes at the international level (Alternate Hydro Energy Centre, IIT Roorkee, 2018). Hydropower is a 100 per cent flexible power source and can play a crucial role in integrating variable RE in the grid. Additionally, SHPs, which are environmentally less damaging, can be used to promote access in remote areas with minimal environmental impact.

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