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Managing the Climate Technology Transition

Ambuj Sagar

Technology has been long viewed as a linchpin of climate action, with the expectation that new and improved technologies will play a significant role in underpinning climate mitigation and adaptation actions, making them cost-efficient and effective (see, for example, Metz et al. 2000). At the same time, it also is understood that addressing the climate problem requires a significant deviation from business-as-usual practices, given the scale and scope of the transformation needed as well as the rate at which it is to happen, if we are to meet the objective of the United Nations Framework Convention on Climate Change (UNFCCC 1992).

This is particularly challenging for developing countries due to the complexities of harnessing and managing technological change and the relatively meagre resources—human, organizational, technical, and financial—often available to them. Simultaneously, these countries also have to address their urgent developmental imperatives, such as economic development, provision of basic needs, and creating/sustaining livelihoods. Furthermore, the choices regarding

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technological pathways and their implementation will vary from country to country depending on their developmental aspirations, resources, and socio-political context, which means that there is no simple way forward. Thus, the topic of technology and climate change is both crucial and demanding for these countries.

This chapter begins by presenting, briefly, a perspective on managing technological change in developing countries and the kinds of resources and capabilities required to do so, juxtaposing it with the role(s) of the UNFCCC in assisting developing countries with the climate technology transition process. It then focuses particularly on India's climate and development challenges (using the energy sector as a case study) and reviews some of the major steps in recent years in addressing these challenges, including in relation to the country's National Determined Contributions (NDCs). It finally discusses some of the key issues in moving forward in a manner that allows for effective engagement with both climate and development objectives in the country (and developing countries more broadly), highlighting the role of both domestic and international actors in this process.

Understanding Technology Transitions in Developing Countries

Harnessing technologies to address mitigation and adaptation challenges in developing countries fundamentally is a process of managing rapid technological change, and doing so under adverse conditions of limited financial, technical, and institutional capabilities. Still, developing countries have no choice but to engage in this process. Doing so effectively requires a clear understanding of how to manage such change within a developing country context; it also requires a broader perspective on the global system of technology innovation, production, and diffusion.

Experience across the world in the past decades across numerous developing countries has shown that harnessing and managing technological change for achieving developmental and other national goals is a tricky process indeed. At the simplest level, it involves developing the capabilities to successfully absorb, implement, and operate or manufacture new technologies domestically. It could be, for example, the introduction of a new process of steelmaking like electric arc furnace, a top pressure recovery turbine for harnessing the waste heat from blast furnaces, or the manufacture of a new design of gas turbine blades. This requires mastering the operations in order to optimally manage these new technologies or processes.

Over time, it is possible to deepen the understanding of these technologies/processes such that one can then begin to improve upon these technologies: at first, incrementally, and then possibly even engage in radical innovation that significantly improves on these existing technologies. In other cases, firms have built up these capabilities by participating in global value chains, enabled by vertical disintegration and globalization, where they have started with manufacture, under contract to transnationals, of specific components of a technological system (say, the display of a phone) or even the assembling of systems (such as computers) and, over time, developing design and innovation capabilities. As might be imagined, this process of technological upgradation is a slow one. In yet other cases, firms might develop organizational or process innovations, such as the Toyota production system that emerged from a particular set of national circumstances, that can offer yet another path to the development of technological capabilities.

Since firms are central actors in development and dissemination of technologies, managing the process of technological change requires the development of suitable capabilities within the firm. However, a large body of work in the last few decades has shown that the development of technological (or innovation) capabilities cannot be undertaken by individual actors by themselves. It really is a process wherein a whole host of actors—firms, academic and research institutions, government agencies, specialized consultancies, law firms, and so on—interact with each other while responding to the technological opportunities and market signals, resulting in flows of knowledge, personnel, and products. Furthermore, these actors are embedded in an institutional environment (where 'institutions' are seen as 'rules of the game', such as culture, norms, and policies) that shapes their behaviour and interactions. These 'national innovation systems' that enable interactive learning lie at the heart of the process of technological capability building and innovation (Lundvall 1992; Nelson 1993).

Another lesson that emerges from past experiences with successful development of national innovation capabilities is the central role of the government in guiding and shaping this process through a range of policies, including support for training of human resources and the generation of knowledge, shaping of market conditions such as development of standards, competition, and trade policies, and, in many cases, even strategically guiding the development of specific industries.

All in all, while harnessing technology can be of enormous value to developing countries to meet specific goals (such as environmental protection) or enable economic development broadly, doing so effectively requires a thoughtful approach on the part of a range of actors, as well as coordination among them, which, as it turns out, is far more difficult than it sounds.

Despite this understanding of the nuances and complexities of the process of managing technological change, many of the discussions on the issue of technology development and transfer, and efforts to promote the same, take a narrow perspective, ignoring the role of the wider set of capabilities needed for effective technology adoption and implementation (see next section; also see Haselip et al. 2015; Ockwell and Mallett 2012). This is also partly driven by what Haselip et al. (2015) refer to as 'technocratic neoliberalism'. At the same time, the world has evolved since the UNFCCC was agreed upon: many developing countries have become major emitters as well as emerging economies that are perceived as being poised to technologically challenge developed economies, especially given the expected enormous growth in the market for climate technologies. This is leading to new forms of protectionism (Lewis 2014).

Developing countries are only a part of the globalized systems of technology development and production; in fact, the centre of gravity of this system lies in industrialized countries. It is those countries that have most of the global technological and financial wherewithal to engage in research and development (R&D), which generates new and improved technologies and reduces their costs, and to engage in early deployment that can help further reduce costs as well as the technical risk of these technologies, making them more amenable to implementation in developing countries.

In other words, the rate and the depth of the climate technology transition in developing countries is coupled to what happens in industrialized countries.

Developing Countries, Climate Technologies, and the UNFCCC

Given the importance of technology for meeting climate goals, there was a clear agreement in the UNFCCC that developed countries will help developing countries with the incremental costs and development of capacities needed for managing their climate technology transitions.

Specifically, the UNFCCC noted, in Article 4.1(c), the commitment to 'promote and cooperate in the development, application and diffusion, including transfer, of technologies' to mitigate greenhouse emission. It also noted:

> … developed country Parties and other developed Parties included in Annex II ... shall also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of implementing measures that are covered by paragraph 1 of … Article [4] ... (Article 4.3, UNFCCC 1992)
>
> … [developed countries] shall 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. [And] … shall support the development and enhancement of endogenous capacities and technologies of developing country Parties. (Article 4.5, UNFCCC 1992)

Despite these lofty goals, the technology issue has received only limited attention for quite some time, with much of the concrete action focusing on Technology Needs Assessments (TNAs; emerging from UNFCCC, Article 4.5) aimed at helping countries determine their technology priorities. Issues like intellectual property rights (IPRs) have often dominated the discussions without leading to productive results and if anything, maybe even distracting from a more thorough and nuanced approach on technology (see Box 23.1).

Box 23.1 Intellectual Property Rights (IPRs)

The IPR issue has been particularly polarized and polarizing in the climate arena, with many developing countries (including India) arguing for an approach to IPRs to facilitate and advance access to climate technologies through, for example, relaxed IPR regimes or funds to help make intellectual property (IP) freely available. Developed countries, on the other hand, have generally espoused a strong IPR regime for providing suitable incentive to innovators as well as facilitating technology diffusion (the assertion being that a strong IPR regime protects transferred technology); they often also suggest that technology transfer is best mediated through the market (since firms are the primary owners of IP). Such differences in perspectives emerge from different discourses on diffusion and development (Ockwell et al. 2010), and also the perceived need seen by many countries to balance the desire of meeting climate goals and the national imperative for building/sustaining an industrial base and protecting/generating livelihoods. At the same time, the mixed empirical evidence, such as the strength of the IP regime not always seen as a necessary condition for technology transfer and IPR being a barrier to technology access in some cases but not others, also leads to lack of consensus on many of these issues. Observers also have pointed out the limitations of focusing on specific issues instead of the broader process (Abdel-Latif 2015) and the range of factors that play a role in effective technology transfer (Ockwell and Mallett 2012). Developing such a broad perspective and strengthening the empirical base on IPR issues—both happening to some extent—could help a move towards a more phased and graded approaches to resolving the IPR issue (Abdel-Latif 2015) and eventually, more effective technology transfer.

Sources: Abdel-Latif (2015); Ockwell et al. (2010); Ockwell and Alexandra Mallett (2012).

The Emergence of the Technology Mechanism

It was only in 2007 that the Bali Action Plan, produced at the 13th Conference of the Parties (COP 13), emphasized the role of enhanced action on technology development and transfer as a key pillar of the process to enable the 'full, effective and sustained implementation of the Convention through long-term cooperative action, now, up to and beyond 2012' (UNFCCC 2007). Developing countries agreed to consider appropriate mitigation actions by developing country parties, but 'supported and enabled by technology, financing and capacity-building, in a measurable, reportable and verifiable manner' (Ott, Sterk, and Watanabe 2008). This eventually resulted in the establishment of the Technology Mechanism at COP 15 (2009) as part of the Copenhagen Accord (formalized in COP 16 in Cancun in 2010).

Specifically, this mechanism envisaged the establishment of the Technology Executive Committee (TEC) as its policy arm and the Climate Technology Centre and Network (CTCN) as its implementation arm. Interestingly, India played an important role in the establishment of the CTCN through its proposal that envisaged the establishment of a global network of climate innovation centres ('CleanNet', Government of India [GoI] 2009) that took a systemic view of the technology innovation process, of the differences in the needs of different developing countries, and of the importance of developing local capacity to support and accelerate technology development, adoption, and implementation (see also United Nations Division of Economic and Social Affairs [UNDESA] 2009).[1] The TEC 'focuses on identifying policies that can accelerate the development and transfer of low-emission and climate resilient technologies' (UNFCCC TT:CLEAR n.d.) and the CTCN 'promotes the accelerated transfer of environmentally sound technologies for low carbon and climate resilient development at the request of developing countries. [It] provide[s] technology solutions, capacity building and advice on policy, legal and regulatory frameworks tailored to the needs of individual countries by harnessing the expertise of a global network of technology companies and institutions' (CTCN 2018a).

The Paris Agreement further emphasized technology as one of the means of implementation, specifically emphasizing strengthening of cooperative action, especially collaborative research, development,

[1] The concept of the climate innovation centres (Sagar, Bremner, and Grubb 2009), upon which this proposal was based, eventually indeed became the basis for a global network of climate innovation centres established by the World Bank (Sagar and Bloomberg New Energy Finance [BNEF] 2010).

and demonstration (RD&D), while also establishing a technology framework (which is yet to fully fleshed out) to 'provide overarching guidance to the work of the Technology Mechanism'; and the Agreement also suggested some links between the Technology Mechanism and the Financial Mechanism (Article 10). Importantly, the Paris COP highlighted the continued increase in the importance of non-UNFCCC institutions and processes on technology issues through, inter alia, the announcement of Mission Innovation (MI), a coalition of 20 major economies that agreed to double their clean energy RD&D (MI 2018a), which is intended to reinvigorate global public energy RD&D investments and strengthen the pipeline of new low-carbon energy technologies. Notably, public energy RD&D spending—a crucial indicator of governments' commitments to the development future climate technologies—by the major industrialized countries, which account for the bulk of the global RD&D expenditures, has declined in recent years (see Figure 23.1); in fact, it has not reached the peaks (in constant dollars) reached in response to the oil crises of the 1970s.

With all of this institutional paraphernalia in place, what is the track record of providing support to developing countries through technology development and transfer, as envisaged in the UNFCCC?

The TEC had published 11 policy briefs as of October 2018, often coupled with background papers, which are intended to provide policy guidance to parties on a range of key technology issues. These include mitigation and adaptation, ranging from sectoral perspectives (such as industrial energy and materials efficiency and technologies for adaptation in water and agriculture) to analytical (results and success factors of TNAs) and cross-cutting (strengthening national systems of innovation to enhance climate action and enhancing access to climate technology financing) perspectives. Importantly, the focus on innovation seems to have become more prominent in the last few years, illustrated, for example, through the language in the Paris Agreement (Article 10) and activities of the TEC, such as the policy brief on technological innovation for the Paris Agreement (TEC 2017). This is consistent with the understanding of the importance of domestic innovation capabilities as being crucial to managing successful engagement with climate technologies (UNFCCC 2014).

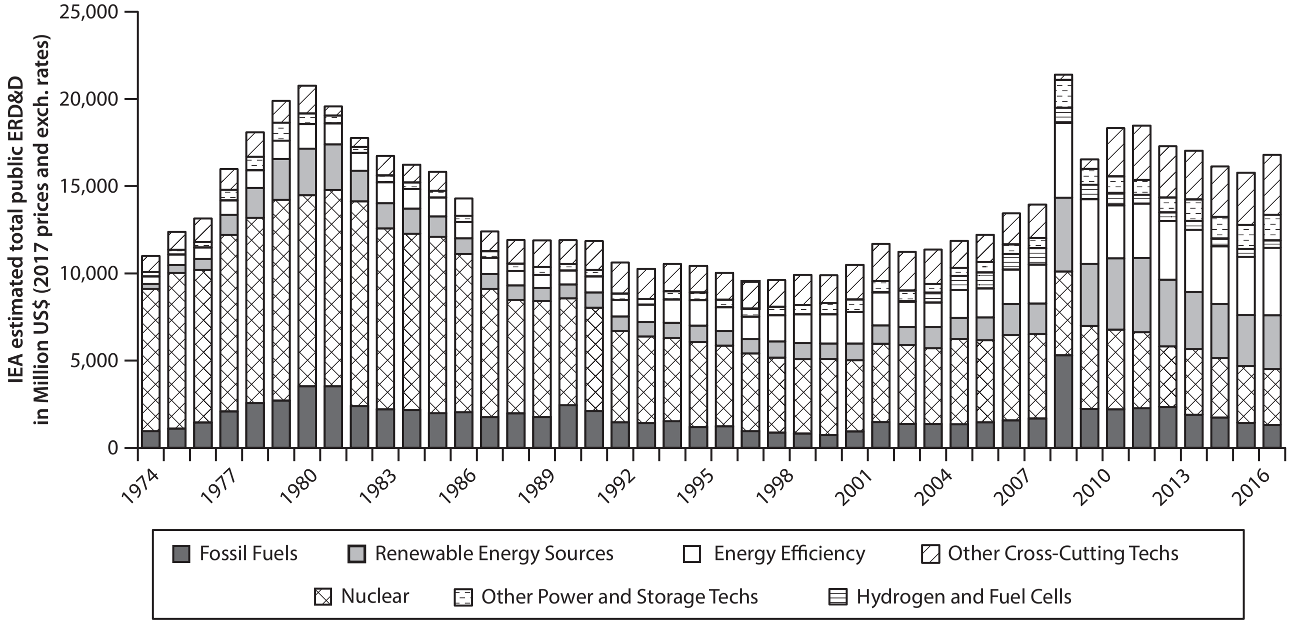

Figure 23.1 Trends in Public Energy RD&D Investments by International Energy Agency (IEA) Countries
Source: IEA (2018b).

After a slow start, CTCN has received 143 requests (as of October 2018), of which 56 have been completed, 39 are under implementation, and 25 are in the design process (with the rest being reviewed) (CTCN 2018b). The pace seems to have picked up with the putting together of the Intended Nationally Determined Contributions (INDCs) for the Paris COP (until the end of the third quarter of 2015, there were 32 requests; a year later, the total number of requests had jumped to 95) (CTCN 2018b). However, it should be noted that the CTCN is on a shoestring budget: its estimated expenditure for 2017 is just over US$8 million (CTCN 2018c), which is miniscule, given that this is the main body under the UNFCCC tasked with providing support to all developing countries for the technological aspects of their climate actions. Of particular importance is the fact that the CTCN does not have any fund allocations through the UNFCCC—it has to depend on donor support, which leads to an unstable funding situation. Also, almost half of funding that it has secured is earmarked (CTCN 2018d). Thus, although the CTCN's activities have grown over time as countries have developed a better understanding of their needs—and therefore what to request of CTCN—and as CTCN has also gained experience in responding to requests, the financial situation of the CTCN necessarily limits the scope of the assistance it can offer.

So, while we do see some evolution and deepening of the UNFCCC approach to assisting developing countries with their technology transition, it should be noted that these efforts are rather limited in relation to the scale of the technology transition challenge. While the TEC has begun to embrace the 'national systems of innovation' approach, it is not clear that this perspective has permeated the 'on-the-ground' efforts intended to support technology development and transfer. Furthermore, the shift towards developing countries taking on ambitious targets makes their climate technology transition process that much more tricky.

Technology Transitions in the Indian Energy Sector

The Energy–Climate–Development Nexus

Since energy use is a key contributor to greenhouse gas (GHG) emissions both globally and in India—it accounted for just over 70 per cent of the country's GHG emissions in 2010, having risen

50 per cent from the preceding decade, according to the first Biennial Update Report (GoI 2015) (and a further 30 per cent between 2010 and 2015 [IEA 2018a])—it appropriately receives a disproportionate focus in GHG mitigation conversations within the climate arena. Technologies play a central role in shaping the energy sector and have, as a result, received significant attention in the climate arena (within both the policy and scholarly domains).

At the same time, provision of adequate, reliable, and affordable energy is a major policy objective for all countries, given the centrality of energy to human, social, and economic development. This becomes particularly salient for India, whose per capita energy and electricity use still is only a fraction of the global average, despite progress in these areas in the recent years. Furthermore, the lack of modern energy access for a significant fraction of the population indicates that ensuring access for all also remains a policy imperative. Both of these, of course, are linked to the issue of affordability.

The Indian policy response towards the energy–climate nexus has been multifaceted and evolving (see Chapter 19 in this volume). Many of the policy initiatives—and indeed the country's NDCs—give prominence to renewables and energy efficiency, reflecting both our recent journey in these areas as well as national priorities. This is particularly apparent with the NDC focus on reduction of the emissions intensity of the gross domestic product (GDP) by 33–5 per cent between 2005 and 2030 and the target of 175 gigawatt (GW) of renewable by 2022 (including 100 GW of solar).[2]

There certainly is a case to be made that the ambitious initiatives and plans have resulted in the beginnings of a significant technological transformation of the Indian energy economy, especially in terms of enhancing energy efficiency and implementing renewables for electricity generation.

Renewable Energy

In the case of renewable energy, the Indian government has used a wide array of policies to promote renewables deployment (see also

[2] Available at http://pib.nic.in/newsite/PrintRelease.aspx?relid=128403; accessed on 10 May 2018.

Chapter 24 in this volume). These include regulatory policies, such as feed-in tariffs, renewable portfolio obligations, tradable renewable energy certificates, and tendering (where reverse auctions for solar projects was a particularly innovative and successful approach), and fiscal incentives, such as investment/production tax credits, reduction in sales tax, and public financing. Although there have been hiccups with some policies, such as the accelerated depreciation on wind turbines which led to a focus on capital investments rather than energy production, overall these policies have been quite successful at accelerating the deployment of renewables in India.

To give a few examples:[3] as of end of 2017, India had 18.5 GW of installed solar power generation capacity, having added 9.2 GW in 2017 (almost all solar photovoltaics [PV]). This was the third-highest solar generation capacity addition globally in 2017 (up from fourth highest in 2016). Our stated target of 100 GW of solar generation capacity by 2022 is certainly greatly accelerating deployment—the addition in 2017 was over double that of the 4.1 GW addition in 2016. However, in terms of total installed capacity, while India is sixth highest in the world, it still remains well behind the leaders—the top four countries all have an installed capacity in excess of 40 GW, with China at 130 GW (of which 53 GW was added in 2017). Having said that, the rise in India's solar generation capacity is quite remarkable given that, in 2007, our installed solar capacity was a meagre 4 megawatt (MW).

In wind power, India had a total installed capacity of almost 33 GW at the end of 2017, with an addition of 4.1 GW in 2017, the fourth highest in the world, with China again at the top with 188 GW. The country's overall wind power installed capacity has increased from 7.8 GW in 2007 to 32.9 GW in 2017, which, although not as impressive as solar, is still almost a fourfold increase over a decade.

How do we interpret these figures? Simply in terms of capacity addition, we can say that the last decade has been transformative in terms of our perspective on renewables, particularly on solar generation technologies. To some extent, the rapid rise in our installed

[3] Renewables capacity data from REN21 (2018).

capacity has been enabled by policies such as reverse auctions that allowed for efficient price discovery (Energy Sector Management Assistance Program [ESMAP] 2013), which has been credited with helping reduce tariffs significantly.[4] In fact, by 2016, the levelized cost of solar energy (weighted average) in India was among the lowest in the world (REN21 2017). However, this was also a period of a global explosion of solar and wind installed capacity, going from 100 GW in 2007 to over 900 GW in 2017 (International Renewable Energy Agency [IRENA] 2018a).

During this period, global solar installed capacity rose from 8.7 GW to 390 GW and wind power from 90 GW to 515 GW (IRENA 2018a). As a result, costs of the technologies dropped significantly: solar PV module costs dropped by 75–80 per cent between 2010 and 2015 (IRENA 2018b); and wind turbine prices dropped by 25–45 per cent (IRENA 2018d). This also allowed the generation costs to reduce substantially, to the extent that they started becoming competitive with conventional fossil fuel. The levelized cost of electricity (LCOE) of solar PV dropped from 0.347 US$/kWh) in 2010 to 0.131 US$/kWh in 2016; and for wind, from 0.071 US$/kWh in 2010 to 0.056 US$/kWh in 2016 (IRENA 2018c). These unprecedented cost reductions also gave a great boost to the country's efforts to enhance renewables capacity.

While India is seen as a major success story on the electricity access front, with over 500 million people having gained access to electricity supply since 2000, when earlier only 43 per cent of the population has such access, most of these gains have come from grid extension rather than implementation of off-grid renewables power systems (IEA 2017a). Thus, the push on renewables is focused more on addressing climate mitigation and energy security rather than energy access. In other words, the accelerated deployment of renewables in the country has perhaps been motivated more by climate concerns than developmental concerns, and has been enabled to a significant extent by global cost reductions, along with deployment policies.

[4] The tariffs are now down to Rs 2.44/kilowatt hour (kWh) (Ministry of New and Renewable Energy 2017).

Energy Efficiency

The country has also made significant progress over the last decade on the energy efficiency front. In fact, there has been forward movement on a range of areas involving a variety of technological domains. These include a standards and labelling (S&L) scheme for energy-efficient household appliances (covering 21 categories of appliances); the Perform–Achieve–Trade scheme that is part of the National Mission on Enhanced Energy Efficiency (NMEEE) and is intended to address industrial energy efficiency in firms in energy-intensive sectors; the Market Transformation for Energy Efficiency (MTEE) that is intended to promote a shift towards more energy-efficient products; and the programme on energy efficiency in buildings.

All of these programmes are intended to facilitate and accelerate the diffusion of energy-efficient technologies and practices, but each programme has taken an approach that is tailored towards the specific nature of that domain. Thus, the S&L programme was intended to both provide information to consumer to help them make more informed choices and to allow the appliance manufacturers to also develop some understanding of, and confidence in, consumer preference for energy-efficient household appliances. Therefore, it started as a voluntary programme and as the market for these energy-efficient appliances became firmer, the labels (and related standards) became mandatory. The Bureau of Energy Efficiency (BEE) estimates that as of March 2017, the S&L programme has led to an avoided generation of capacity of almost 23 GW.[5]

The MTEE programme focuses on cost reduction as way to promote the uptake of new technologies. The Bachat Lamp Yojana under this programme focused on energy-efficient compact fluorescent lamp but was replaced by the Ujala programme that focused instead on the more efficient light-emitting diodes (LEDs). Here, a combination of market aggregation and bulk procurement by Energy Efficiency Services Limited (EESL) helped reduce the price of LED bulbs from Rs 310 to Rs 38, while demand rose 50 times between 2014 and 2017 (Chunekar, Mulay, and Kelkar et al. 2017). As of 31 October 2018, over 310 million LEDs had been distributed, with

[5] Available at https://www.beeindia.gov.in/; accessed on 15 May 2018.

an estimated savings of over 40 million kWh per year.[6] The Super-Efficient Equipment Programme (SEEP) aims to provide incentives to manufacturers of equipment to develop altogether new products (such as super-efficient fans) that are also affordable. The centerpiece of the building energy efficiency programme is the Energy Conservation Building Code that specifies particular standards of energy-efficient performance for new commercial buildings above a certain size.

As in the renewables area, we see that the focus is on the implementation of new or improved technologies, starting with the early market deployment or market creation (or even development of new products, as in the case of SEEP), and then promoting their widespread diffusion. The main drivers of the renewables programme are climate mitigation and energy security; energy efficiency efforts also contribute to enhancing energy availability by allowing of a greater provision of energy services with the same generating capacity.

The Big Picture?

Yet, despite all these impressive achievements a larger strategy sometimes does not seem to be clear. For example, in the Solar Mission, Phase 1, the domestic content requirement intended to help build local industry did not really serve the purpose. Furthermore, it was challenged by the United States (US) in the World Trade Organization (WTO), leading to an adverse ruling against India (Clover 2016; FE Bureau 2018). In fact, India has really not had much success in building a solar manufacturing industry, despite these aggressive deployment targets—there is only one Indian manufacturer in the top 20 suppliers worldwide (whereas in comparison, seven of the top 10 manufacturers in 2016 were Chinese, with the country accounting for 65 per cent of the global shipments) (Natural Energy Hub 2018). China's share of global PV manufacturing has risen from 12 per cent in 2006 to 48 per cent in 2016 (IEA 2017b). The industry leaders are not very optimistic about developing significant domestic manufacturing capacity in the near term. A recent survey indicated that a majority of renewable energy chief executive officers

[6] Available at http://www.ujala.gov.in; accessed on 31 October 2018.

(CEOs) felt that Indian would have less than 3 GW of integrated manufacturing capacity by 2022 (Bridge to India 2018b).

Sometimes, policy signals are mixed: the safeguard duty being considered by the government, driven by the Make in India, may be counterproductive in terms of achieving NDC targets in the required time frames (Bridge to India 2017a, 2017b, 2018a). While the country does have a major wind power firm (Suzlon) that is in the top 10 globally in terms of cumulative installed capacity, in 2016, it was only the sixteenth-largest supplier (*Windpower Monthly* 2017). Notably, China, again, has four firms in the 10 largest suppliers (with the remaining all being from the US or Europe).

In other words, we have not been very successful at leveraging our markets or deployment to build a successful industrial base. China, on the other hand, has taken a systematic and long-term perspective in building up its renewables industrial and innovation base (see, for example, Dai and Xue 2015), with remarkable results.

At the same time, we also have not been innovating much in climate-related technologies, whereas many Organisation for Economic Co-operation and Development (OECD) countries and even South Korea and China have significantly invested in R&D and building up innovation capabilities in these areas, as evinced by the trends in patent application data (see Figure 23.2). Specifically for renewable technologies, where India is making a major push, our performance again is rather dismal. In the area of solar power generation, where we have extraordinarily ambitious goals in terms of deployment, our record at innovation barely registers, compared to even some other major emerging economies or newly industrialized countries. Between 2009 and 2013, we had 239 patents filed in solar power; equivalent numbers for South Korea and China for the same period are 6,906 and 52,758 respectively (IRENA 2018e). This is the case even in wind power, where we have had a much longer track record: we filed 140 wind energy-related patents over this period; again, South Korea and China filed 6,906 and 17,806 patent applications (IRENA 2018e).

Thus, while India has been investing heavily on the climate technology front, particularly on renewables and energy efficiency, our focus is mostly on rapid deployment without paying adequate attention to building a large and dynamic base in these emerging

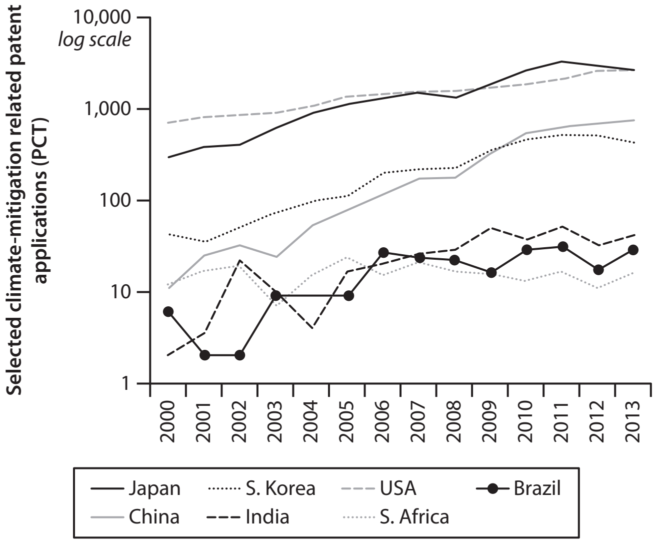

Figure 23.2 Trends in Climate-Related Patent Applications Filed under Patent Cooperation Treaty (selected by priority date and applicants' country of residence)

Note: Patent categories include climate change mitigation technologies related to buildings, energy generation, transmission or distribution, transportation, production, or processing of goods; technologies related to capture, storage, sequestration, or disposal of GHGs; and water-related adaptation technologies.
Source: OECD 2018.

industries, or building a comprehensive energy innovation system that would encompass a range of activities (see next section).

Yet another area involving low-carbon energy technology involves a nascent effort to enhance the country's clean energy R&D. As one of the founding members, India is an active participant in MI. As part of our efforts in MI, we intend to raise our clean energy RD&D expenditure from an estimated US$72 million to US$200 million by 2020. Of the seven challenges agreed upon by MI countries, India is taking the lead in three, namely, smart grids, off-grid access to electricity, and sustainable biofuels (MI 2018b). To promote collaborative RD&D, an international call was launched, which was open to all MI countries, to partner with India as the lead. Eighteen projects are being supported in the first round (nine in smart grids, nine in off-grids) with a total investment of US$10 million. The expectation is to have scalable and demonstrated off-grid solutions in two years; and the smart grid partnerships have the same timeline but without the demonstration goal. The Indian government is also investing US$7.5 million in a smart grid research partnership with the US as part of the second phase of the Joint Clean Energy R&D Centre—this investment is being matched by Indian private partners, with a similar total amount of US$15 million from the US side. The Indian government has also just launched a major clean energy incubator in partnership with private investors (Ministry of Science and Technology 2018). It is not very clear, though, how these R&D efforts will be linked to deployment activities and whether there is a larger strategic perspective on climate technology innovation in the country.

Looking Ahead

While concerns about climate change continue to increase and the discussions in the climate arena continue to aim to meet the UNFCCC objectives, most observers agree that meeting a 2 degree Celsius (°C) goal (leave alone 1.5°C) is increasingly unlikely (see, for example, Rogelj et al. 2016).

While technology does not offer a silver bullet to the climate problem, it certainly will be part—and an important part—of our arsenal to address climate change and its impacts. However, in order to fully harness the potential contribution of technology in this arena, developing and developed countries as well as relevant international actors (UNFCCC and others) will all have to do their part.

Industrialized countries could do much by increasing their public investments in climate technology innovation (and MI is hopefully already a good step in this direction) and send clear and consistent market signals through strong and stable climate policies. Both of these will help stimulate private investments in climate technology innovation, and eventually contribute to accelerated technology development and deployment in these countries. These, in turn, will increase the feasibility of implementing these technologies in developing countries, both through greater availability and cost reduction of climate technologies.

India and other developing countries have begun to show significant appetite for engaging with the climate issue through often-ambitious domestic goals and actions. As they do this, it will be helpful to take a systematic approach to realizing the full benefits of climate technologies. This requires aligning and synergizing climate and development goals (and resolving tensions, where needed) to get the most from their climate technology efforts. This may mean, for example, prioritizing actions that provide local air pollution and climate mitigation benefits. It may mean a focus on enhancing climate resilience of the agricultural sector that contributes to food and livelihood security, or it may mean leveraging climate technology efforts not just to decarbonize the electricity sector but also build-up an industrial base that can contribute to economic development.

Capabilities to manage technological change will play a key role in meeting climate and development goals that involve technology (R. Lema and A. Lema 2012; A. Lema and R. Lema, 2013), which require building national systems of innovation (with the understanding that different countries may have different capability needs, based on their climate technology goals and their economic and human resource context). This requires paying attention to all parts of the innovation system, including technical research capacity to develop new technologies or modify/adapt existing ones to local use conditions, the ability to facilitate the market deployment of these technologies, and eventually, diffusion at scale, which is necessary for getting the desired mitigation or adaptation outcomes.

Perhaps the most important is the strategic and coordination capability that is able to help analyse the possibilities of synergizing climate and developmental aspirations and how to translate these into specific objectives, selecting the appropriate technology pathways, developing strategies for effective implementation, and learning how to learn from their (and others') experiences. This dimension is where developing countries are often the most lacking. However, as the historical experience with newly industrialized economies—and most recently, China—has shown, a strategic and systematic approach can yield rich benefits in terms of meeting not just climate goals but also, at the same time, reducing air pollution or building a dynamic industrial and innovation base, although it still has some way to go in catching up with the innovation leaders (Nordensvard, Zhou, and Zhang 2018).

Building up these innovation systems and capabilities for managing a climate technology transition will require efforts by both developing countries as well as the international community, as spelled out in Table 23.1. Developing country actors necessarily have to play a central role. This may involve government support for foundational activities such as R&D, or development of human resources, or broad policies to ensure availability of finance for various stages of technology commercialization, or sectoral policies to catalyse and deepen markets for low-carbon technologies. It may also require firm investments in building up their internal capabilities. Further, it may involve academic/training institutions helping advance knowledge that is relevant to specific innovation objectives, along with helping impart suitable skills to the workforce. Governments also play an important role in facilitating interactions and linkages between these various actors (such as industry and academia) and addressing innovation gaps.

International actors can also help in this process of innovation system building by providing specific technical support in various stages of the innovation cycle, whether it is technology opportunity and options analysis, technology modification/adaptation or demonstration, or setting up production facilities. They can help with development of suitable policies too, drawing on effective international experiences and helping tailor to local contexts. In fact, the TEC and the CTCN are moving in this direction, both through the provision of synthesized knowledge and advisory services as well as facilitating engagement by a wider range of actors in this process. Yet, the focus on helping strengthen strategic planning capabilities to select transition pathways that best address climate and developmental challenges in the context of specific national aspirations and abilities remains mostly absent.

All in all, managing the climate technology transition to achieve effective and efficient outcomes consistent and synergistic with developmental needs requires significant and thoughtful effort on the part of numerous actors—both public and private—at various levels, ranging from multi/plurilateral to national to sub-national.

Table 23.1 Strengthening Key Elements of National Innovation Systems

	Strategic Analysis and Coordination	**Basic and Applied Research**	**Technology Development/ Adaptation (Including Demonstration)**	**Market-Focused Product and Delivery-Model Development/ Adaptation**	**Commercialization**	**Large-Scale Diffusion**
Focus of NSI strengthening efforts	Development of priorities based on mitigation and adaptation options, development needs, and local capabilities and resources; identification of impelementation pathways and innovation gaps; coordination of activities across innovation cycle	Scientific research capabilities	Scientific, engineering, and design capabilities; understanding of users and markets as well as product-user/market ineractions		Manufacturing capability; creation of early markets; risk mitigation for early adopters/users	Refinement of delivery/ business models; policies for large-scale deployment; programme/ policy review and feedback
National-level activities	Identification of agency/ies to	Domestic R&D funding;	Financial and technical support for technology translation		Availability of financing for scale-up	Policies to support

(*cont'd*)

Table 23.1 (*cont'd*)

	Strategic Analysis and Coordination	**Basic and Applied Research**	**Technology Development/ Adaptation (Including Demonstration)**	**Market-Focused Product and Delivery-Model Development/ Adaptation**	**Commercialization**	**Large-Scale Diffusion**
	play strategic and coordination role(s)	Support for higher education and specific skills training	and product development and demonstration		of manufacturing and risk mitigation of early adopters	diffusion; demand creation
Possible international activities	Technical support for (climate and development) opportunity analysis; technology options landscaping, and local capability analysis; Implementation pathway design; Innovation gap assessment	Financial support for scientific research collaborations; human resource training; joint technology development/adaptation		Financial & technical support and training for product demonstration/ trials, user feedback, and design	Financial & technical support for manufacturers; technical support and training for financial institutions and policy-makers for market and risk-mitigation-instrument design; "best practice" knowledge sharing	Technical support and training for policy-makers; 'best practice' knowledge sharing

Source: Compiled by the author.

If we are to be successful at addressing climate change, we have to significantly raise the ambition to build the capabilities to manage the climate technology transition. It clearly is not easy, but there is no choice.

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