Chapter 7

What Are the Roles of National and International Institutions to Overcome Barriers in Diffusing Clean Energy Technologies in Asia?: Matching Barriers in Technology Diffusion with the Roles of Institutions

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Additional information is available at the end of the chapter

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1. Introduction

While the international negotiation on climate change does not make much progress in designing the post-Kyoto scheme, technology innovation and transfer is becoming a central issue in the negotiation. In Cancun in 2010, the parties agreed to organize the Technology Executive Committee (TEC) and the Climate Technology Centre and Network (CTCN) (UNFCCC 2011). The developed countries have committed to provide $100 billion yearly to assist the developing countries in mitigation and adaptation through the Green Climate Fund (UNFCCC 2011).[1] The scheme of the Fund is currently under discussion at the Transitional Committee for the design of the Green Climate Fund.

This paper consists of two parts. The first part of the paper attempts to show a broad landscape of barriers in technology diffusion in the developing countries by addressing two levels of barriers. The first level is about the barriers that are commonly observed among the developing countries (Section 2.1). The paper classifies these barriers into technological, financial and institutional barriers. The second level is about the barriers that are technology-specific (Section 2.2 and 2.3). Section 2.3 summaries the results of previous case studies that were

1 The text of the COP document states that [The Conference of the Parties] recognizes that developed country Parties commit, in the context of meaningful mitigation actions and transparency on implementation, to a goal of mobilizing jointly USD 100 billion per year by 2020 to address the needs of developing countries (paragraph 98); agrees that, in accordance with paragraph 1(e) of the Bali Action Plan, funds provided to developing country Parties may come from a wide variety of sources, public and private, bilateral and multilateral, including alternative sources (paragraph 99); and decides that a significant share of new multilateral funding for adaptation should flow through the Green Climate Fund (paragraph 100).

conducted to uncover technology-specific barriers in diffusing clean energy technologies in Asia. These case studies include both technologies for industrial use such as wind, bio-energy and building energy efficiency and technologies for individual use such as LED (Light Emitting Diode) and Photovoltaic (PV) panels. It also contains technologies at the innovation stage such as Integrated Gasification Combined Cycle (IGCC) and Carbon Capture and Storage (CCS). Section 2.3 presents an analysis of the barriers through a comparison of the results of the case studies.

The second part of the paper explores roles of institutions to overcome identified barriers in diffusing clear energy technologies in Asia (Section 3). It addresses theoretical discussions on functions (or roles) of international and national institutions in technology innovation. It then attempts to match the barriers in technology diffusion identified in Section 2 with the functions of national and international institutions. The results of matching indicate that there are important roles of institutions both at the early and advanced stages of technological development to encourage R&D cooperation from the public site (early stage) and enhance the enabling environment and facilitate finance for the technologies (advanced stage).

2. Studies on barriers in technology diffusion in the developing countries

Understanding barriers in technology diffusion lead to important lessons in designing policy instruments and institutions for diffusing clean energy technologies in the developing countries. With this understanding, researching about barriers has been part of the tasks under the UNFCCC as well as United Nations Environmental Program (UNEP) (UNFCCC 2011; UNEP Risø Centre on Energy, Climate and Sustainable Development 2011). Painuly indicates that there are several levels to explore and analyze such barriers. Painuly adds that the first level is a broad category of barriers and the lower levels include more detail and specific barriers (Painuly 2001). Section 2.1 illustrates barriers at the first level. Section 2.2 lists case studies that address barriers at a lower level that are more technology specific. Section 2.3 presents an analysis of the barriers through a comparison of the results of the case studies.

2.1. Barriers commonly observed among the developing countries

The barriers at the first level are the barriers that are commonly observed among the developing countries. There are substantial amounts of research projects that have attempted to identify the barriers at this level including Painuly (2001), OECD/IEA (2001), Painuly and Fenhann (2002) and Raddy and Painuly (2004). Table 1 summaries key barriers identified through these and other research. The barriers are classified into technological, financial and institutional barriers[2,3]:

2 It is not possible to clearly distinguish barriers into the three classifications. Many barriers relate to more than two classifications. Under the circumstances, the paper attempts to fit each barrier into the most appropriate classification.

3Table 1 includes some technology-specific barriers as well as country/region-specific barriers. It is also noted that the table contains selected major barriers only.

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Barriers	Barriers	Explanations	Source(s)
Technological	Limited capacity to assess, adopt, adapt and absorb technological options	• These technologies are primarily targeted at rural areas or poor customers, who have limited capacity to absorb these technologies. There is a general resistance to change, which is magnified due to lack of capacity to understand, adopt and adapt the technologies for greater benefit. The capacity constrains are not only linked to its use but in its production. There is limited manufacturing capacity and as a result not much innovation has taken place. Scale-up of manufacturing and therby reduction in the associated costs has not taken place. (Ravindranath and Balachandra pp.1010) • Technology not freely available in the market, technology developer not willing to transfer technology, problems in import of technology/ equipment due to restrictive policies/taxes etc. (Painuly pp.82)	(Ravindranath and Balachandra 2009) (Painuly 2001)
	Lack of knowledge of technology operation and management	• Lack of knowledge of technology operation and management as well as limited availability of spare parts and maintenance expertise (Doukas et al p.1139)	(Doukas et al 2009) (Luken and Rompaey 2008) (OECD/IEA 2001)
	Lack of skilled personnel/training facilities	• This can be a constraint for producers (Painuly p.80) • Lack of experts to train, lack of training facilities, inadequate efforts. (Painuly pp.83) • In China and much of South East Asia, there is a need for technically trained people and people with strong management skills. Where training of local workforce is provided, it should be recognized that Asians tend to learn more effectively by coping, rather than as individuals, when local language is used and with a practical "hands-on" approach. Also the issue of training in intellectual property rights is important. This is a long term issue but will be important for long term changes in attitudes to intellectual property rights in China. (Guerin pp.71)	(Painuly 2001) (Usha and Ravindranath 2002) (Jagadeesh 2000) (IPCC 2000) (Guerin 2001) (Worrell et al. 2001) (Flamos et al. 2008) (OECD/IEA 2001)
Technological	Lack of standard and codes and certification	• Product quality and product acceptability is affected. (Painuly pp.80) • Lack of institution/initiative to fix standards, lack of capacity, lack of facilities for testing/certification. (Painuly pp.83) • A degree of standardization would improve the penetration of photovoltaics (PVs), it would enable PVs to become more user friendly. (Oliver and Jackson pp.381) • Lack of standardization in system components resulting from the wide range in design features and technical standards, and absence of long-term policy instruments have resulted in manufacturing, servicing and maintenance difficulties of wind turbines. (Jagadeesh pp. 162)	(Painuly 2001) (Oliver and Jackson 1999) (IPCC 2000) (Joanna 2007) (Jagadeesh 2000) (OECD/IEA 2001) (Oltz and Beerepoot 2010)
Financial	Lack of access to financing	• High first costs and investments associated with mass manufacturing remain as barriers. Both the users and the manufactures have very low capital. This problem is further	(Ravindranath and Balachandra 2009) (Painuly 2001)

Barriers	Barriers	Explanations	Source(s)
		accentuated by the rigid lending procedures that limited access to financing even when financing is available on standard norms. (Ravindranath and Balachandra pp.1010) • Capital costs may go up due to increased risk perception. Adverse effect on competition and efficiency. (Painuly pp.79) • Small and medium scale enterprises (SMEs) above all lack the finances for cleaner technologies, but also contact with larger technology manufacturers and formal information channels. (UNFCCC 2003, p.12) • Limited capital availability will lead to high hurdle rates for energy efficiency investments because capital is used for competing investment priorities…High inflation rates in developing countries and CEITs, lack of suffcient infrastructure increase the risks for domestic and foreign investors and limit the availability of capital (Worrell et al 2001, pp.6-7) • International public finance is no longer going into energy (electricity) infrastructure, which is now seen as of interest to the private sector under the neo-liberal or privatization agenda (Thorne, p.3)	(UNFCCC 2003) (Worell et al. 2001) (Jagadeesh 2000) (IPCC 2000)(Thorne 2008)
Financial	Potential lack of commercial viability	• In general, technology imported from industrialized countries is more efficient but also more expensive than technology manufactured locally, and it therefore requires higher initial investment costs. This is of particular importance for the transfer of environmentally sound technologies. Furthermore, as a result of their typically early commercialization stage, environmentally sound technologies are often considered riskier than existing commercial technologies (Karakosta et al., p.1551)	(Karakosta et al, 2010)
	Lack of financial institutions to support renewable energy technologies, lack of instruments	• Adverse effect on competition and efficiency. (Painuly pp.79) • Under-developed capital markets, restricted entry to capital markets, instruments unfavorable regulations. (Painuly pp.83)	(Painuly 2001) (Jagadeesh 2000)
Institutional	Uncertain governmental policies	• Many of the renewable energy technologies in India are still in the development stage. There are no sufficient governmental regulations/ incentives to stimulate the adoption of renewable energy technologies by business and industries. They include: (a) lack of explicit national policy for renewable energy at end-use level; (b) incomplete transition to cost-based electric tariffs for most residential and some industrial customers; (c) poor availability of credit to the purchase of renewable energy technologies in the economy; and (d) lack of application of modern management skills in energy development agencies. (Reddy and Painuly pp.1436)	(Redd and Painuly 2004) (Painuly 2001) (Worell et al. 2001) (Schneider and Hoffman 2008) (Doukas et al. 2009) (Karakosta et al. 2010) (OECD/IEA 2001)

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Barriers	Barriers	Explanations	Source(s)
		• It creates uncertainty and results in lack of confidence. May also increase cost of project. (Painuly pp.80) • Uncertainty in policies, un-supportive policies, inadequately equipped governmental agency, red tape, lack of governmental faith in RETs, lack of policies to integrate renewable energy technologies products with the global market, inadequately equipped governmental agency to handle the product.(Painuly pp.84) • National trade and investment policies may limit the inflow of foreign capital. This might be a barrier to technology transfer (Worrell et al. 2001, p.7) • Uncertain ownership, lack of intellectual property-rights protection and unclear arbitration procedures. (OECD/IEA p.14)	
Institutional	Lack of infrastructure	• Problems related to availability of infrastructure such as roads, connectivity to grid, communications, other logistics. (Painuly pp.84) • The places where energy infrastructure has not yet been extended to are, by-and-large, areas where people are poor and unlikely to be able to cover the costs of infrastructure, nor would the users be able to consume sufficient service to make the investment financially feasible alone. Perversely, these are the development niches where many of the immature environmentally sound technologies may already provide least energy cost options. (Thorne pp.3-4)	(Painuly 2001) (Thorne 2008)
	Lack of information and awareness	• It increases uncertainty, and hence costs. (Painuly pp.79) • Lack/low level of awareness, inadequate information on product, technology, costs, benefits & potential of the renewable energy technologies, O&M costs, financing sources etc. Lack of agencies, or agencies ill equipped to provide information. Also, feedback mechanism may be missing or inadequate. Lack of knowledge/access to renewable energy technologies resource assessment data, implementation requirements. (Painuly pp.82) • It is generally believed that the adoption of renewable energy technologies are often not undertaken as a result of lack of information or knowledge on the part of the customer, or a lack of confidence in obtaining reliable information. Households and small firms and commercial establishments face difficulties in obtaining information on renewable energy technologies compared to the simplicity of buying conventional energy technologies. There is hardly any knowledge (software and/or hardware) about renewable energy technologies that is readily available and easily accessible for the consumers. Under these circumstances, information collection and processing consume time and resources which is difficult for small firms and individual households. (Reddy and Painuly pp.1435)	(Kathuria 2002) (IPCC 2000) (Painuly 2001) (Reddy and Painuly 2004) (UNFCCC 2003) (Worrell et al. 2001) (Flamos et al. 2008) (Karakosta et al. 2010) (Luken and Rompaey 2008) (OECD/IEA 2001)

Barriers	Barriers	Explanations	Source(s)
Institutional	Lack of consumer acceptance	• Adoption of renewable energy technologies are generally influenced by consumer perceptions of the quality and usefulness of these items when compared to conventional technologies. Renewable energy technologies are often perceived to be used with discomfort or sacrifice rather than as providing equivalent services with less energy and cost. Also, while purchasing a technology, consumers take the advice of their friends rather than obtaining information from the experts and take decisions which may not be economically rationale. (Reddy and Painuly pp.1436-1437) • Unknown product, aesthetic considerations, products lacks appeal, resistance to change, cultural reasons, high discount rates of consumers, inadequate information. (Painuly pp.84) • Many potential users of sustainable energy technologies have no or little experience with their application and the assistance provided in the development of such technologies is insufficient. Moreover, dissemination of EU experience sustainable energy technology implementation to other countries in the world has been limited (Flamos, p.5)	(Reddy and Painuly 2004) (Painuly 2001) (Flamos et al. 2008)

Table 1. Barriers (technological, financial and institutional) observed among the developing countries

Technological barriers include not only limited access to the international technology market but also limited capacity to assess, adopt, adapt and absorb technological options (Ravindranath and Balachandra 2009; Painuly 2001). As the table indicates, lack of knowledge of technology operation and management as well as lack of skilled personnel/training facilities can be a major barrier for successful diffusion of clean energy technologies (Doukas et al. 2009; Luken and Rompaey 2008; Painuly 2001; Usha and Ravindranath 2002; Jagadeesh 2000; IPCC 2000; Guerin 2001; Worrell et al. 2001; Flamos et al. 2008; OECD and IEA 2001). Lack of standard and codes and certification can be a barrier too since product quality and product acceptability is affected (Painuly 2001).

A lack of financing is a major part of the financial barriers (Ravindranath and Balachandra 2009; Painuly 2001; UNFCCC 2003; Worell et al. 2001; Jagadeesh 2000; IPCC 2000; Thorne 2008). Ravindranath and Balachandra (2009) states that “high first costs and investments associated with mass manufacturing remain as barriers. Both the users and the manufactures have very low capital. This problem is further accentuated by the rigid lending procedures that limited access to financing even when financing is available on standard norms.” At this point, Karakosta et al. (2010) further elaborates that “in general, technology imported from industrialized countries is more efficient but also more expensive than technology manufactured locally, and it therefore requires higher initial investment costs. This is of particular importance for the transfer of environmentally sound technologies.” Lack of financial institutions to support renewable energy technologies as well as lack of financial instruments is also highlighted as part of the financial barriers (Painuly 2001; Jagadeesh 2000).

Institutional barriers include lack of explicit forms of institutions such as goals, policies, regulations and incentive programs as well as lack of implicit form of institutions such as information, awareness, social acceptance, and conditions of the surrounding environment. As for explicit forms of institutions, Painuly (2001) points out uncertainty in policies, unsupportive policies, inadequately equipped governmental agency, red tape, lack of governmental faith in renewable energy technologies, lack of policies to integrate renewable energy technologies products with the global market, inadequately equipped governmental agency to handle the product. Lack of infrastructure is another aspect of institutional barriers, pointed out by Painuly (2001), that is, problems related to availability of infrastructure such as roads, connectivity to grid, communications, and other logistics. As for implicit form of institutions, Painuly (2001) points out lack/low level of awareness, inadequate information on product, technology, costs, benefits and potential of the renewable energy technologies, O&M costs, financing sources. Flamos et al. (2008) addresses lack of customer acceptance as an institutional barrier. It points out that "many potential users of sustainable energy technologies have no or little experience with their application and the assistance provided in the development of such technologies is insufficient" (Flamos et al. 2008).

Section 2.1 addressed barriers that are commonly observed among the developing countries. Section 2.2 illustrates case studies addressing technology-specific barriers.

2.2. Case studies addressing technology-specific barriers

There are a number of research initiatives that have attempted to identify barriers through the case study approach. The advantage of the case study approach is that it helps to uncover technology-specific barriers, while other studies looking at the developing countries or clean energy as a whole may overlook these barriers. Table 2 lists the case studies that are reviewed in this paper[4]:

	Research organization/individuals	Information on each case study		Sources
		Country	Technology	
Case study 1	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Wind power	Ockwell, D., J. Watson et al. (2009)
Case study 2	SPRU at University of Sussex and TERI in India	India	Integrated Gasification Combined Cycle (IGCC)	A: Ockwell, D., J. Watson et al. (2007) B: Ockwell, D., J. Watson et al. (2009)

4 This paper looks into key case studies in Asia only, although there are case studies being conducted in other parts including South America and Africa.

	Research organization/individuals	Information on each case study		Sources
		Country	Technology	
Case study 3	SPRU at University of Sussex and TERI in India	India	LED (Light Emitting Diode)	Ockwell, D., J. Watson et al. (2007)
Case study 4	SPRU at University of Sussex and TERI in India	India	Biomass	Ockwell, D., J. Watson et al. (2007)
Case study 5	SPRU at University of Sussex and TERI in India	India	Hybrid vehicles	A: Ockwell, D., J. Watson et al. (2007) B: Ockwell, D., J. Watson et al. (2009)
Case study 6	SPRU at University of Sussex and TERI in India	India	Photovoltaic (PV) panels	Ockwell, D., J. Watson et al. (2009)
Case study 7	International Institute for Industrial Environmental Economics (IIIEE) at Lund University	Developing countries	Carbon Capture and Storage (CCS)	Dalhammar, C. et al. (2009)
Case study 8	IIIEE at Lund University	Developing countries	Building energy Efficiency	Dalhammar, C. et al. (2009)
Case study 9	United Nations Department of Economic and Social Affairs (DESA)	China	Wind power	United Nations, DESA
Case study 10	Lewis J.	India and China	Wind power	A:Lewis, J., (2007a) B:Lewis, J., (2007b)
Case study 11	Mizuno E. (on a publication by UNEP Risø Centre on Energy, Climate and Sustainable Development)	India	Wind power	Mizuno. (2011)
Case study 12	(Ravindranath and Rao on a publication by UNEP Risø Centre on Energy, Climate and Sustainable Development)	India	Bioenergy	Ravindranath and Rao (2011)
Case study 13	Suzuki, M., Okazaki B., and Jain K.	Thailand	Biogas	A: Suzuki, M., Okazaki B., and Jain K. (2010) B: Jain K., Okazaki B., Suzuki, M. (2011)

Table 2. List of case studies reviewed in this paper

The Science and Technology Policy Research (SPRU) at University of Sussex and TERI in India jointly conducted a research project looking into barriers through several case studies in India including wind power, IGCC (Integrated Gasification Combined Cycle), LED (Light Emitting

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Diode), biomass, hybrid vehicles and photovoltaic (PV) panels (Case Study 1-6) (Ockwell, D., J. Watson et al. 2007; Ockwell, D., J. Watson et al. 2009). This is the most comprehensive research project thus far looking into barriers through the case study approach. The IIIEE at Lund University in Sweden conducted several case studies including Carbon Capture and Storage (CCS) and building energy efficiency (Case Study 7 and 8) (Dalhammar, C. et al. 2009). In addition, there are a number of case studies that are conducted on the individual basis (Case Study 9-13).

It is observed that many of these case studies are conducted in China and India. This is probably relating to the fact that these two countries have the largest potentials in diffusing clean energy technologies among the developing countries. Another point to note among these case studies is that two popular targets for a case study are wind power and bio-energy (including biomass/ biogas). This is possibly due to the fact that these two technologies are at the stage where they are successfully implemented in some cases but there are still facing barriers to point out for further diffusion. On the other hand, Table 2 also indicates that there are a variety of research interests with respect to the targeted technologies for analysis. Some research interests are geared toward to the technologies at the innovation stage such as IGCC and CCS. Some research interests are directed to the products for individual use rather than industrial use such as hybrid vehicles, LEDs, and PV. The diversity in the targeted technologies for analysis may lead to interesting finding about barriers.

2.3. Comparative study on technology-specific barriers

Section 2.3 compares the results of the case studies identified in Section 2.2. Table 3 summarizes the results of the studies:

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
Case study 1	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Wind power			• IPR is the main issue. The transfer of technological know-how to Indian companies was restricted. (p.116) • The high cost of IPR acquisition. (p.118) • In the joint ventures and collaborative ventures, it had been noticed that the [Indian] companies had to depend on their European counterparts for all technical aspects and even operation and maintenance issues. (p.117)

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
						• It is very important to develop the indigenous capacity for technology development and manufacturing. Equally important would be to incentivize innovations from the viewpoint of national priority. (p.120)
Case study 2	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	IGCC (Integrated Gasification Combined Cycle)	• Limited amount of testing of IGCC that has been done with Indian grade coal. All IGCC demonstration plants to date have been based on coals with different characteristics to Indian coal, especially ash content and ash fusion temperature.(A:p.58) • The long-term success of technology transfer in technologies such as gasification relies on building technological capacity within recipient countries. (A:p.58)	• The two key risks associated with IGCC are high capital costs and the lack of reliable operational history. The risks associated with high capital cost are amplified by the limited operational history and the new nature of this particular application of gasification. (A:p. 58)	• Premature to comment on IPR issues related to IGCC, since this technology is not considered to be commercial globally. (B:p.110)
Case study 3	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	LED (Light Emitting Diode)	• Although the technical competency in India exists in the fields of material science, engineering, control electronics and other relevant fields, they have to be nurtured in the context of LED technology.(p.72) • Indigenous capacity is to be developed quickly	• No clear indication about the type of market that exists for LED. (p.69) • The leading players worldwide are not considering India as a potential region for investment as they do not see any market in India at present. (p. 72)	• It is a highly protected technology. As there are various processes involved in manufacturing LED chips, each process is patented and requires huge investment. At present the cost of investing in both chip manufacturing and resolving the IPR issues is substantially high compared to importing the chips. Therefore in India, the chips are imported

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				so that when technology is transferred it can be taken up. (p.74)	• Import of LED is much easier and cheaper than to manufacture it because of IPR issues. (p.69) • LED chip manufacturing requires several processes. Each process involves energy as well as capital-intensive equipment. The existing players in India are relatively smaller in size and are not ready/capable of investing huge amounts for LED chip manufacturing. (p.72)	primarily from China, Taiwan, Japan, the US and other countries. (p.72)
Case study 4	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Biomass	• The opportunity cost of power outages at briquetting plants. In many regions of India, electricity from the grid cuts out for hours at a time. (p.80) • The lack of accessibility to power presents problems. In India, where electricity connections are often unavailable in rural locales, the power requirement for briquetting machines could prove to be a major barrier to establishing plants in remote areas even if they are rich in	• Entrepreneurs and manufacturers alike identified working capital as a primary barrier to successful commercialization of briquettes. (p.79) • Banks are reluctant to finance agro residue projects. These products have traditionally been viewed as waste, with no collateral value. (p. 79) • Because of the low repayment record, briquetting has developed a poor	• As long as ram and die machines were selling and operating at an acceptable level, manufacturers were not willing to begin a new endeavor that carried with it some measure of uncertainty. (p.77) • The raw material situation is quite different in India, where sawdust is a commodity rather than a waste product and is in fact widely used, unprocessed, as a cooking fuel. (p.78) • The statistics about India's vast biomass resources and statements about the "virtually unlimited" supply of biomass in India can be

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				agricultural waste products. (p.80) • In the early days of biomass briquetting, Indian machines experienced more breakdowns and required more maintenance than anticipated. Indian entrepreneurs are experiencing high maintenance costs even with ram and die machines. (p.80)	reputation and been labeled as an irresponsible undertaking. Most stakeholders interviewed felt that subsidies are not the answer for the briquetting industry and that briquetting ventures will have to stand on their own. (p.80)	misleading....Competing uses for rice husk, coffee waste, bagasse, mustard stalks, and many other kinds of waste have caused the prices to rise dramatically. (p.79) • The lack of networking and information sharing among the manufacturers. (pp. 81-82)
Case study 5	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Hybrid vehicles	• It is as much a concern for governments in developed countries to encourage the development and uptake of this low carbon technology as it is for governments in developing countries. At present, however, all of the companies owning commercially viable hybrid technologies are based in developed countries. (A: p.89) • If foreign firms supplying hybrid technology maintain a high level of integration in their approach to transferring the technology this could make it more difficult for knowledge regarding the technology to diffuse		• Host country companies may be able to develop technological capacity through involvement in supplying parts for, or maintenance services for vehicles fitted with imported hybrid technology. Even so, there may be IPR issues associated with imitating patented hybrid drive trains. A better understanding of the extent to which IPRs might limit the development of new hybrid drive trains by developing country based manufacturers is an important issue that warrants further investigation.(A: p.95) • IPRs are dominated by a concentrated set of foreign companies rather than domestic players in India. Patents exist in a number of areas, including batteries, electric motors and power electronics, engines and system

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	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				within the recipient country. (A: pp.94-95)		integration. In addition, patents exist for both products and processes. Thirdly, there is a general consensus by firms and other players (e.g. academic institutions) that they must work together to make advances in this area. (B: pp.84-85)
Case study 6	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Photovoltaic (PV) solar	• Mature production technology for silicon cells is available on the market without licenses since related patents have expired. (P.65) • Most Indian companies have focused on producing silicon solar modules, the fourth stage of the value chain. This is changing however, as an increasing number of Indian firms are planning on producing the entire PV value chain and are expanding into other areas, such as thin film technology. (P.65)		• Many informants also argue that recent PV industry development is largely driven by two additional relatively new national policies: 1. The Government of India's Semiconductor Policy Guidelines in September 2007, which is essentially a tax holiday until March 2010 and 2. Electricity Generation Based Incentives (GBI) providing a subsidy for grid connected PV power plants.(pp.74-75) • Regarding policies to support technological capacity, there are almost no policies in place to encourage collaboration at the national or international level.(p.76)
Case study 7	International Institute for Industrial Environmental Economics (IIIEE) at Lund University	Developing countries	Carbon Capture and Storage (CCS)	• An immediate conceptual difficulty with CCS is that it is to be made up of an integrated suite of technologies. Moreover, institutional components addressing the CCS chain will also be a crucial system component. As CCS is not		

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				market mature and does not have any commercial examples in operation, this report cannot address CCS system transfer. Rather, one example of an incipient technology transfer framework is noted here there are two transfer projects within its remit. (p.69)		
Case study 8	International Institute for Industrial Environmental Economics (IIIEE) at Lund University	Developing countries	Building energy efficiency	• A fragmented and complex construction process, with an inherent split incentives dilemma: Building markets prefer low initial costs, and get no benefits from life cycle energy savings, whereas users may be willing to pay a high upfront cost if significant economic benefits are possible during the use phase. (p. 92) • Uncertain energy savings from equipment due to the influence of users behavior. (p.92) • A lack of formal training and capacity building among construction workers makes it difficult to introduce new techniques and innovation in construction work. (p.93) • Lack of awareness of the potential and	• High initial costs for energy efficient and renewable energy equipment. This means that payback periods are long (up to 30 years) for many investments. (p.92) • The limited importance of energy expenditures as compared other household improvement or financial concerns. (p. 92)	• A lack of awareness and information of the opportunities, technologies and low cost of installing energy saving features. (p.92) • The lack of government interest in energy efficiency and renewable energy, and insufficient enforcement of existing policies also present barriers to energy saving in the building sector. • Poor enforcement of building codes and other mandatory standards, even among front-runner countries. (p.92) • Poor market surveillance and/or certification measures mean that low- quality products can enter the market and destroy consumer confidence in the technology. • Building codes tend to be less effective, due to insufficient implementation and enforcement, and corruption f or instance, in China the compliance rate is much higher

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	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				importance of energy efficiency measures, lack of financing, and lack of qualified personnel (p.92) • Mandatory energy audits and similar tools require training of auditors, however, there is often a lack of monitoring of quality of audits.(p.93) • Lack of evaluation and follow-up is a major concern.(p.93)		in large cities than in rural areas.(p.93) • Adaption to the local situation is crucial, not least for utility demand-side management (DSM) programs, and projects should be designed to fit the local situation.(p.93)
Case study 9	United Nations Depertment of Economic and Social Affairs (DESA)	China	Wind power			• Notably, the Chinese Government is considering the implementation of local IP requirements for wind power in an attempt to push international companies to transfer more technology. Such stipulations on IP requirements could be contested by international companies under the World Trade Organization or by simply limiting new FDI in this sector. (p.30)
Case study 10	Lewis J.	India and China	Wind power	• It took China and India less than 10 years to go from having companies with no wind turbine manufacturing experience to companies capable of manufacturing complete wind turbine systems, with almost all components produced locally. This was done		• Both China and India have excellent wind resources and aggressive, long-term government commitments to promote wind energy development...Some of the early support mechanisms in China and India, in particular, led to market instability as developers were faced with regulatory uncertainty, especially concerning pricing

Research organizations/ individuals	Information on case study		Barriers		
	Country	Technology	Technological barriers	Financial barriers	Institutional barriers
			within the constraints of national and international intellectual property law, and primarily through the acquisition of technology licenses or via the purchasing of smaller wind technology companies. While both companies pursued similar licensing arrangements to acquire basic technical knowledge, Goldwind's technology development model lacks Suzlon's network of strategically positioned global subsidiaries contributing to its base of industry knowledge and technical capacity. • Suzlon's growth model particularly highlights an increasingly popular model of innovation practices for transnational firms…Its expansive international innovation networks allow it to stay abreast of wind technology innovations around the world so that it can then incorporate into its own designs through its extensive research and development facilities. (B)		structures for wind power. In the early years of wind development in China and India, difficulties also resulted from a lack of good wind resource data, and a lack of information about technology performance stemming from little or no national certification and testing. • Policy reforms in the electric power sectors of both countries…has led to a series of regional renewable energy development targets in India, national targets in China, and additional financial support mechanisms for wind in particular. There are two key differences in the policy support mechanisms currently used in China and India: (1) China's recent reliance on local content requirements to encourage locally sourced wind turbines, which does not exist in India, and (2) India's use of a fixed tariff price for wind power, versus China's reliance on competitive bidding to set the price for most of its wind projects. (B)

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	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
Case study 11	Mizuno E. (on a publication by UNEP Risø Centre on Energy, Climate and Sustainable Development)	India	Wind power	• External factors such as the rapidly increasing high-tech characteristics of wind energy technology systems and the fast structural transformations of the industry at the frontier made it difficult for India to cope with the various changes. (p.46)		• A large market size and market certainty and continuity were lacking in India: even though many market demand characteristics were similar to those in the frontier market, without a sizable market and its own pulling power, technology upgrading through replicable technology transfer did not happen. The small market made all demands for technological improvement insignificant.(p.44) • India's experiences with wind technology have some important lessons for how to encourage private-sector replicable technology transfers from developed to developing countries. The small market size, the non- performance-oriented market mechanism, the policy inconsistency, the institutional problems of the power sector, the lack of technological capabilities to meet the increasingly higher quality requirements of wind energy technology and the persistent infrastructure deficiencies in India, along with tighter technology controls by technology providers and collaborators, all contributed to the increasing technology gaps in both product and capabilities with the frontier after the mid-1990s.(p.46)

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
Case study 12	Ravindranath and Rao (on a publication by UNEP Risø Centre on Energy, Climate and Sustainable Development)	India	Bio-energy (including biomass gasification, biomass combustion, biogas, efficient cook stoves)	• Gas cleaning systems are still not robust and hence high in terms of maintenance (p.136) • Poor understanding of managing moisture content (p.136) • Biomass drying techniques are not well established (p.136) • Lack of knowledge (p. 137) • Uncertainty and distrust in the source of information (p.137) • Inadequate training, capacity-building and user-education programs. (p.137)	• Dual fuel systems do not seem economically feasible, and hence the focus is on producer gas. But 100% producer gas engines still are not very common, not readily available at all capacities (p.136) • The high initial costs of bio-energy technologies are perceived by many as a key barrier to the penetration of bio-energy technologies vis-a-vis conventional technologies. The principal capital cost of biomass power projects includes the costs of the gasifier, the engine generator, civil construction, biomass preparation unit, electricity distribution network and electrical and piping connections to the site of gasifier installation and need subsidization (p.138). • Mainstream financial institutions have been reluctant to take risks in lending due to a long history of poor	• The abundance of biomass was initially the push [by the government] needed to promote bio energy technologies. There was therefore little or no interaction with rural communities in formulating the technologies. (p.135) • The institutional framework in India currently lacks a viable strategy to empower local communities. Community organizations and institutions are rarely involved in the planning, implementation and management of, say, the rural electrification program through biomass gasifiers. The failure of a large number of small village systems, such as biogas plants, and stand-alone gasifiers is to a large extent related to the fact that there is no coordinated local, institutional and government support. (p.137) • A critical problem has been overcoming issues arising out of bureaucracy…Many developers have mentioned the significant periods of delay in obtaining technical approvals.(p.137) • Climate change is not being seen an immediate threat or priority for rural communities. (p.137) • Social behavior and expectations.(p.137)

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
					recovery of loans in rural area.(p.138)	• Absence of an enabling environment. (p.137)
Case study 13	Suzuki, M., Okazaki B., and Jain K.	Thailand	Biogas	• There is no centralized information and orientation regarding biogas technologies and the equipments that are available . It is also very difficult to find data related to projects' performance and information about projects that have already been implemented. (A: p. 20) • There is a lack of awareness. There is also a lack of public support in terms of information, and little information regarding biogas is transferred. In addition to this, since the degree of education of the managers is low, the technology of anaerobic digesters and biogas production appears to the managers as being very complex issues. (A: p. 21) • The anaerobic digesters are complex and sensitive systems. Often, even the managers do not understand how it works. So, due to a low understanding of the new processes, managers rely heavily on the	• Most of the time, the focus of companies is to maximize the profit over a short period. Frequently the managers have little to no information about biogas or anaerobic digester systems and the subsequent technical implications and costs. (A: p.17) • Most technologies for wastewater systems and biogas came from developed countries (Parr et al., 2000). Proper transfer and adaptation to tropical climates requires investment and will result in costs being incurred (importation taxes, logistics, training, etc.). (A: p.20) • The tapioca and palm oil industries are traditional agro-industries, often managed by families with a basic application of management principles under a simple organizational	• The managers do not seek professional support when researching biogas technology due to financial reasons. On the other hand, often the managers do not know where to search for the information they need, since there are no standard guidelines or publicly available information about biogas performance and technologies. There is no support from the government and there are very few initiatives in R&D in regions where biogas is prominent. (A: p.18) • The starch and palm oil industries are traditional agro-industries, normally run by families in an informal manner and structure. In addition, many companies have an incorrect perception of the reality of the market. In these circumstances, a long term strategy or the development of a business plan is not realistic, nor is it a common practice for these industries. (A: pp.19-20)

Research organizations/ individuals	Information on case study		Barriers		
	Country	Technology	Technological barriers	Financial barriers	Institutional barriers
			technology provider. In order to remain focused on the core production process, or to save costs, often the managers do not provide adequate or appropriate training for the operators on the new wastewater/ biogas processes and systems. (A: p.22)	structure. In addition, biogas production is not considered as important as the core business. Thus, on many occasions the operators are not motivated to perform due to a lack of a company performance reward policy or due to a different remuneration compared to his coworkers in the core production business. (A: p.21)	

Table 3. Results of case studies

2.3.1. Barriers for technologies for industrial use: Wind, bio-energy, and energy efficient building

Starting from wind power, the results of Case Study 1 and 11 suggest that there are institutional and technological barriers for diffusion in India and China. According to Case Study 1, the cost of IPR acquisition is a major barrier in India. Case Study 1 points out that "the [Indian] companies had to depend on their European counterparts for all technical aspects and even operation and maintenance issues." Case Study 11 addresses a similar view that technologically, the wind power in India still hinges upon the external development of the industry. It states that "external factors such as the rapidly increasing high-tech characteristics of wind energy technology systems and the fast structural transformations of the industry at the frontier made it difficult for India to cope with the various changes." On the other hand, Case Study 10 provides a positive evaluation on the development of local wind power production in India and China. It observes that "it took China and India less than 10 years to go from having companies with no wind turbine manufacturing experience to companies capable of manufacturing complete wind turbine systems, with almost all components produced locally." The results of these case studies on wind in India and China indicate that although there is a great level of success in producing indigenous local power technologies, there are still technological as well as institutional barriers for further diffusion in these countries.

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Bio-energy is similar with wind power with respect to its successful implementation in the developing countries. On the other hand, the results of the case studies on bio-energy suggest that it faces different types of barriers for further diffusion. According to Case Study 12, implementations of bio-energy projects in India have met both technological and institutional barriers in the operational phase such as poor understanding of managing moisture content, lack of knowledge, uncertainty and distrust in the source of information and inadequate training, capacity-building and user education programs. The case study on biogas power generation in Thailand comes to a similar conclusion (Case Study 13). It recognizes the "no centralized information and orientation regarding biogas technologies and the equipments" as well as the lack of understanding and awareness as the major barriers for successful implementation of the technologies. The results of these case studies suggest capacity building and knowledge development play an important role in the successful implementation of bio-energy technologies.

The case study on building energy efficiency also suggests that the technological barriers such as lack of knowledge and awareness as well as the institutional barriers such as lack of information on available technologies are major barriers in this case too (Case Study 8). The results of Case Study 8 highlights, as the technological barriers, uncertain energy savings from equipment due to the influence of users behavior, a lack of formal training and capacity building among construction workers, lack of awareness of the potential and importance of energy efficiency measures, lack of financing, and lack of qualified personnel. In the case of building energy efficiency, lack of institutional support is another area of institutional barrier. It points out the lack of government interest in energy efficiency and renewable energy, and insufficient enforcement of existing policies, poor enforcement of building codes and other mandatory standards as major institutional barriers.

2.3.2. Barriers for technologies for individual use: Hybrid vehicles, LEDs, and PV

Other than wind power, there are studies that identify IPRs as a major barrier for technological diffusion. The case study on hybrid vehicles in India is one of them. It indicates that IPRs are the major barrier in this case as well since "IPRs are dominated by a concentrated set of foreign companies" (Case Study 5). It states "all of the companies owning commercially viable hybrid technologies are based in developed countries." The results of the case study on LED also suggest that IPRs are the key barrier for the diffusion of LED (Case Study 3). They case study demonstrates that "it is a highly protected technology. As there are various processes involved in manufacturing LED chips, each process is patented and requires huge investment. At present the cost of investing in both chip manufacturing and resolving the IPR issues is substantially high compared to importing the chips." In this regard, there may be important lessons to learn from the previously mentioned case on wind power for producing local technologies despite the existence of IPRs-related barriers. In the case of LED, however, the results of the study indicate there is a separate key barrier for the diffusion of the technology in India. The case study identifies the size of the market as a major financial barrier for technology diffusion in India. It states that there is "no clear indication about the type of market that exists for LED." Furthermore, it stresses that "the leading players worldwide are not considering India as a potential region for investment as they do not see any market in India at present."

Interestingly, in contrast to hybrid vehicles and LEDs, the results of the case study on PV in India suggest that IPRs are not an essential barrier for the diffusion of the technology in India (Case Study 6). It maintains that mature production technology for silicon cells is available on the market without licenses since related patents have expired. Moreover, an increasing number of Indian firms are planning on producing the entire PV value chain and are expanding into other areas, such as thin film technology.

2.3.3. Barriers for technologies at the innovation stage: IGCC and CCS

The results of the case studies on IGCC and CCS indicate that technological barriers are dominant for technologies at the innovation stage (Case Study 2 and 7). Financial and institutional barriers are not relevant for the technologies at the innovation stage. As for CCS, Case Study 7 states "As CCS is not market mature and does not have any commercial examples in operation, this report cannot address CCS system transfer." As for IGCC, Case Study 2 states "It might be premature to comment on IPR issues related to IGCC, since this technology is not considered to be commercial globally".

Thus far, Section 2.3 discussed technology-specific barriers. Another barrier, which this paper could not address this time, are country-specific barriers. It is recognized that in order to design proper policy instruments and institutions, understanding of barriers that are specific to a certain country or region is equally important. With this regard, Case study 10 is an exception among the selected case studies in highlighting several differences between India and China as to how these two countries overcome barriers to diffuse wind power technologies. It demonstrates that "there are two key differences in the policy support mechanisms currently used in China and India; 1) China's recent reliance on local content requirements to encourage locally sourced wind turbines, which does not exist in India; and 2) India's use of a fixed tariff price for wind power, versus China's reliance on competitive bidding to set the price for most of its wind projects." In addition, it discusses key differences on corporate strategies between two Chinese and Indian wind turbine manufacturing firms. This type of comparative studies are much needed in order for us to have better understanding of barriers in the diffusion of clean energy technologies.

3. Roles of institutions to overcome identified barriers in diffusing clear energy technologies in Asia

Section 2 presented the barriers commonly observed in the developing countries as well as the technology-specific barriers. Section 3 explores roles of institutions to overcome these barriers in diffusing clear energy technologies in Asia. Section 3.1 addresses theoretical discussions on the functions of international and national institutions in technology innovation. Section 3.2 attempts to match the barriers in technology diffusion identified in Section 2 with the functions of national and international institutions.

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3.1. Theoretical discussions on the functions of international and national institutions in technology diffusion

There are theoretical explorations about the roles of institutions in changing a system in the area of innovation economics and innovation theory. For Joseph Schumpeter, who is the patron of innovation economics, an evolving institution is an important factor for economic growth. Inspired by Schumpeter, scholars in innovation theory attempt to define functions or roles of institutions in changing a system. Borrás, for example, defines that they are 1) competence-building and generation of incentives including production of knowledge, diffusion of knowledge, financial innovation, alignment of actors, guidance of innovators; 2) generation of incentives and reduction of uncertainty including appropriation of knowledge, reduction of technological diversity; and 3) establishment of limits and reduction of uncertainty including reduction of risk and control of knowledge usage (Borrás 2004). Another example is a study by Suurs and Hekkert. According to Suurs and Hekkert, there are seven functions of institutions including 1) entrepreneurial activities; 2) knowledge development; 3) knowledge diffusion; 4) guidance of the search; 5) market formation; 6) resource mobilization; and 7) legitimization (Suurs and Hekkert 2009).

There are also research initiatives that attempt to understand the roles of institutions in diffusing clean energy technologies both at the national and international level, although the focus of research is geared toward the national level rather than the international level. At the international level, a study conducted by de Coninck et al. is an example of such research (de Coninck et al. 2008). This study classifies technology-oriented agreements (TOAs) addressing climate change into four broad categories including 1) knowledge sharing and coordination; 2) research, development and demonstration (RD&D); 3) technology transfer; and 4) technology deployment mandates, standards, and incentives (de Coninck et al. 2008). According to a more recent study by Benioff et al., there are three roles of international institutions for innovation and transfer of clean energy technologies including research, development, and demonstration (RD&D) cooperation, enhancement of enabling environment, and financing facilitation and support (Benioff et al. 2010).

It is important to note here that the roles of institutions differ along the technological development of clean energy technologies. At the early stages of technological development, institutional support for the empowerment of research groups is needed to demonstrate and deploy technologies (Suzuki 2012). As the case studies on CCS and IGCC indicated in Section 2, the technologies at the innovation stage require strong R&D efforts to remove technological barriers in order to move forward to the next stage. At the innovation stage, the empowerment of network between international and local research groups is needed to enhance the R&D efforts, especially with a stronger initiative from the public side (Benioff et al. 2010; Morey et al. 2011; UNFCCC 2009).

At the advanced stages of technological development, institutional support as well as policy arrangement for the involvement of the actors in the private sector such as project developers, equity investors, manufactures, and commercial banks is essential in technology diffusion

(GtripleC 2010; Carmody et al. 2007). Providing economic incentives for the private sector are an important measure to improve investment conditions and encourage its participations. Therefore, clean energy and carbon finance vehicles may be also effective to introduce technologies at the advanced stage. For example, the economic policy instruments such as CDM may take an instrumental role. If they are designed well, the schemes under discussion for the post-Kyoto regime such as the bilateral carbon crediting mechanism and the sectoral or program-based crediting mechanism can be also a good policy candidate for technology diffusion. At the national level, an introduction of a feed-in-tariff program has received greater attentions among the developing countries, while other economic instruments such as subsidy, emissions trading, and renewable energy certificate scheme can be also recognized as possible policy options. The investment schemes such as co-investments and loans or risk guarantees may help to reduce risk associated with investment from the private sector (Suzuki 2012). In addition, such an arrangement for building a partnership between the private and the public (Public-Private Partnership: PPP) may leverage the interests of the private sector in developing technologies that would not be attracted to clean energy technologies otherwise.

3.2. Matching the barriers in technology diffusion with the functions of national and international institutions

Section 2.3 illustrated technology-specific barriers among different technologies. Section 3.2 attempts to match those barriers with the functions of national and international institutions that were identified in Section 3.1.

The case studies on wind as well as on hybrid vehicles and LED indicated that difficulties associated with IPRs are major barriers in technology diffusions. Indeed, IPRs are complex issues and providing opportunities to learn about the issues can be an important institutional arrangement as the first step. Ockwell, D., J. Watson et al. (2009), on the case of wind in India, states that “there was a need to create awareness among the industry players who do not have deeper understanding of implications of IPR rules and regulations, including those in the context of WTO regime.” Preparing patent pools for licensing inventions is often discussed as a necessary arrangement in diffusing clean energy technologies but it requires careful institutional design not to remove incentives for the private sector and discourage its innovational efforts. At the international level, the World Intellectual Property Organization (WIPO) can facilitate such venues for the private sector in the developing countries to learn about IPRs-related issues.

The case study on LED identified the size of the market as a major barrier. This case, together with the case on building energy efficiency, also pointed out high capital cost as a major barrier. In order to overcome these barriers, the roles of institutions in facilitating and supporting finance are important. On LED, Ockwell, D., J. Watson et al. (2007) states that “as government is already promoting PV integrated energy efficient lighting systems for rural lighting applications, incentives could be provided for LED based PV integrated systems.” As for the case on biomass, low priority in finance is recognized as a major barrier. In this case, knowledge sharing and coordination is the key in overcoming the barrier in technology diffusion. At this point, Ockwell, D., J. Watson et al. (2007) demonstrates that "all the briquetting machine manufacturers felt that there is practically no collaboration or communication among them. The lack of networking and information sharing among the manufacturers is one of the greatest constraints to diffusion of technological developments in the sector. Hence projects aimed at promoting knowledge sharing among the manufacturers and users of biomass briquettes will be very useful for the sector".

The case studies on bio-energy, biomass, and building energy efficiency all emphasized that lack of the enabling environment is the key barrier in technology diffusion. The case study on bio-energy in India highlighted "poor understanding of managing moisture content, lack of knowledge, uncertainty and distrust in the source of information and inadequate training, capacity-building and user education program" as a major hindrance. The case study on biomass in Thailand pointed out a lack of formal training and capacity building among construction workers, lack of awareness of the potential and importance of energy efficiency measures, lack of financing, and lack of qualified personnel. In order to overcome these barriers associated with a lack of the enabling environment, the case study on bio-energy in India suggested promoting collaboration between industry and academia, for field demonstrations, and promoting feedback and communication between developers and implementers (Ravindranath and Rao 2011). It stated that "the development of training schemes could provide a route to alleviating this skill shortage. It is important to ensure that all staff involved in training and development have been adequately trained themselves. Use of R&D institutions in training could be beneficial" (Ravindranath and Rao 2011).

As for the technologies at the early stage of technological development, the cooperation in R&D between the pubic and the private sectors as well as the cooperation between local and overseas actors are inevitable in order to overcome technological barriers. As emphasized earlier, the strong initiatives from the public side are needed since it is difficult to expect the private sector to play an important role if the business model is not yet visible. The case study on CCS indicated that "given current policy and market conditions, carbon markets appear marginal or inadequate for CCS applications such as industrial-scale demonstration plants to be economically viable without (potentially significant) additional support" (Dalhammar, C. et al. 2009). The case study on IGCC concluded that "one possible approach to overcoming the risks of high capital costs is for government to share the funding of demonstration activities with industry… Financial support from developed to developing countries would be needed to provide for incremental costs and technology transfer fees, through international financing mechanism" (Ockwell, D., J. Watson et al. 2007; Ockwell, D., J. Watson et al. 2009).

Table 4 illustrates both identified barriers and roles of institutions to overcome the identified barriers

	Early stage	Advanced stage
Barriers	• **Technological barriers**: Case Study 2 (IGCC), 7 (CCS) • High capital cost: Case Study 2 (IGCC)	• **IPRs**: Case Study 1 (wind), 9 (wind), 11 (wind), 5 (hybrid vehicles), and 3 (LED) • Market size: Case study 3 (LED) • High capital cost: Case study 3 (LED), 8 (building energy efficiency) • Low priority in finance: Case Study 4 (biomass) • Lack of enabling environment: Case Study 8 (building energy efficiency), 12 (bio-energy),13 (biogas) • Lack of policy support: Case Study 6 (PV), 8 (building energy efficiency)
Roles institutions	In theory… • R&D cooperation • Financing facilitation and support ("resource mobilization" and "market formation") • Entrepreneurial activities	In theory… • Knowledge sharing and coordination (including "guidance of the search") • Enhancement of enabling environment (including "legitimization") • Financing facilitation and support (including "market formation" and "resource mobilization")
	Identified roles	**Identified roles**
	R&D cooperation • Public-supported centers for technology innovation and transfer. • Strengthening bilateral and multilateral network for R&D. Financing facilitation and support • Technology funding mechanisms for the developing country participants in R&D. • Global clean technology venture capital fund. Entrepreneurial activities • Clean energy incubator incentives.	Knowledge sharing and coordination/ enhancement of enabling environment • Patent pools for licensing inventions. • Various capacity building programs covering a whole supply-chain. • Business matching venues among various business actors such as project developers, manufacturers and investors (local and international). Financing facilitation and support • Various clean energy finance and carbon finance vehicles including CDM, bilateral crediting scheme, co-benefit approach at the int'l level, feed-in-tariff, subsidy at the national level. • Co-investments, loans or risk guarantees. • Public-Private Partnerships (PPPs).

Table 4. Identified barriers and roles of institutions to overcome the identified barriers

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4. Conclusion

This paper consisted of two parts. The first part of the paper attempted to show a broad landscape of barriers in technology diffusion in the developing countries by addressing two levels of barriers: generic barriers and technology-specific barriers (Section 1 and 2). Section 2.3 summarized the results of previous case studies that were conducted to uncover technology-specific barriers in diffusing clean energy technologies in Asia.

The second part of the paper explored roles of institutions to overcome the identified barriers in diffusing clear energy technologies in Asia (Section 3). It attempted to match the barriers in technology diffusion identified in Section 2 with functions of national and international institutions. The results of matching indicated that there are several different roles of institutions including the role to encourage R&D cooperation from the public site for the technologies at the early stages of technological development and the role to enhance the enabling environment and facilitate finance for the technologies at the advanced stages of technological development.

It is recognized that the existing institutions both at the national and international levels have already been working to overcome barriers in diffusing clean energy technologies. For example, at the national level, the governments in the developing countries are conducting various capacity building programs to enhance knowledge of the private sector about clean energy technologies. At the international level, the financial institutions such as the World Bank and Asian Development Bank are facilitating financial support to encourage diffusion of clean energy technologies. At the innovation stage, there are both bilateral (such as the Global CCS Institute for building a network between Australia and the developing countries) and multilateral (such as the Asia-Pacific Partnership on Clean Development and Climate concluded in April 2011) network to encourage technology innovation. Further research is needed to investigate whether these existing institutions are playing a role in overcoming the barriers that were illustrated in this paper.

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