The Kyoto mechanisms and the diffusion of renewable energy technologies in the BRICS

Isabel Maria Bodas Freitas, Eva Dantas, Michiko Iizuka

Cite as: Bodas Freitas, I.M., E. Dantas and M. Iizuka (2012). The role of global institutional frameworks on the diffusion of renewable energy technologies in the BRICS countries. Energy Policy, 42, 118–128.

The Kyoto mechanisms and the diffusion of renewable energy technologies in the BRICS

Isabel Maria Bodas Freitas[a,b] , Eva Dantas[c,d*], Michiko Iizuka[e]

[a] Grenoble Ecole de Management, 12, rue Pierre Sémard, BP 127, 38003 Grenoble Cedex 01, France
[b] DISPEA, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy
[c] German Development Institute (DIE), Tulpenfeld 6, D – 53113, Bonn, Germany
[d]SPRU, The Freeman Centre, University of Sussex, Falmer, Brighton BN1 9RF, UK
[e] United Nations University (UNU-MERIT), Keizer Karelplein19, 6211TC, Maastricht, The Netherlands

Abstract

This paper examines whether the Kyoto mechanisms have stimulated the diffusion of renewable energy technologies in the BRICS, i.e. Brazil, Russian, India China and South Africa. We examine the patterns of diffusion of renewable energy technologies in the BRICS, the factors associated with their diffusion, and the incentives provided by the Kyoto mechanisms. Preliminary analysis suggests that the Kyoto mechanisms may be supporting the spread of existing technologies, regardless if such technologies are still closely tied to environmental un-sustainability, rather than the development and diffusion of more sustainable variants of renewable energy technologies. This raises questions about the incentives provided by the Kyoto mechanisms for the diffusion of cleaner variants of renewable energy technologies in the absence of indigenous technological efforts and capabilities in sustainable variants, and national policy initiatives to attract and build on Kyoto mechanism projects. We provide an empirical analysis using aggregated national data from the World Development Indicators, the International Energy Agency, the United Nations Framework Convention on Climate Change and secondary sources.

Keywords: renewable energy; technology diffusion; Kyoto Mechanisms; BRICS.

[*] Corresponding author: E-mail address: eva.dantas@die-gdi.de (Eva Dantas). Tel.: +49 (0) 228 94927 171; fax: +49 (0) 228 94927 130.

1. Introduction

This study examines the diffusion of renewable energy technologies in a group of fast growing countries, Brazil, Russia, India, China and South Africa (BRICS), and the role of the Kyoto mechanisms in their diffusion. It focuses on the following research question: have the Kyoto mechanisms stimulated the diffusion of sustainable energy technologies in BRICS? We develop an analytical framework based on the diffusion literature, which we operationalize by decomposing the research question in three sub-questions. We examine the patterns of diffusion of renewable energy technologies in the BRICS in relation, particularly to whether these countries are lagging behind the developed countries in the use of renewable energy. We investigate the role of factors proposed in the literature that support the diffusion of renewable energy technologies, and also look at the type of incentives that the Kyoto mechanisms have created for their diffusion.

Based on their accelerated economic growth and associated environmental burdens, BRICS face major challenges to maintain their rapid growth without proportionately large increases in carbon emissions, i.e. to avoid reproducing a Kuznets curve (O'Conner, 1996; World Bank, 2003). The relocation of many carbon-intensive manufacturing activities from industrialized to developing countries to obtain cost and environmental advantages or to enter into new industries has exacerbated this problem for the BRICS (van der Horst and Hovorka, 2009; Kuchler, 2010). The massive shift in industrial production from industrialized to developing countries has been accompanied by increasing and concerted demands and political pressure from the former for the developing countries to increase their environmental protection efforts and embark on more sustainable development pathways (Weiss and Jacobson, 1998; Blackman and Sisto, 2006).

In this context, the Kyoto mechanisms, created as cooperative arrangements involving the industrialized and the developing countries, are supposed to enable the former to extract the benefits from developing countries to meet their emissions reduction commitments and to allow the developing countries access to more sustainable technologies (UNFCCC, 2010). However, as is the case with other large efforts, the Kyoto Protocol mechanisms are aimed at addressing environmental problems by changing the form in which the world economy accounts for environmental damages and may have unintended effects. At the time of writing, we simply do not know enough about the effectiveness of the demand-pull measures created by the Kyoto Protocol mechanisms for shaping the pace and direction of technology diffusion and, especially, renewable energy technologies. It is unclear whether the Kyoto mechanisms are creating incentives for the diffusion of more sustainable technologies that will allow the BRICS to move to more sustainable growth pathways or favour lock-in to conventional technology variants and environmentally unsustainable pathways. This uncertainty about the incentives provided by the Kyoto mechanisms for 'eco dumping' of emissions problems by the developed countries rather than for emissions reduction and diffusion of sustainable technology, warrants closer examination of the incentives that are being created beyond the explicit and implicit objectives of the mechanisms.

The literature focuses on the effects of the Kyoto mechanisms on emissions reductions, sustainability, and the origin of technology sources, but there are other factors (including the host countries' existing reliance on renewable energy sources) that may encourage the diffusion of renewable energy technologies and which require investigation. The literature shows that clean development mechanisms (CDM) and joint implementation (JI) projects often involve the use of non-sustainable technologies and practices, and their balance with emissions reduction is not always positive (Dechezlepretre et al, 2008; Doranova, 2009;

Espinola-Arredondo and Munoz-Garcia, 2009; Klepper and Peterson, 2006; Popp, 2008). Also, most of the technologies exploited in these projects are not imported from the developed countries, but were already in use in the developing world (Dechezlepetre et al., 2008; Klepper and Peterson, 2006; Doranova et al., 2010). In addition to focusing on emissions reduction, sustainability and the origins of the technology, initial adoption levels and other factors that support the diffusion of renewable energy technologies in emerging economies, and the types of incentives the Kyoto Mechanisms are creating for their diffusion, need to be examined. This paper addresses these rather neglected issues.

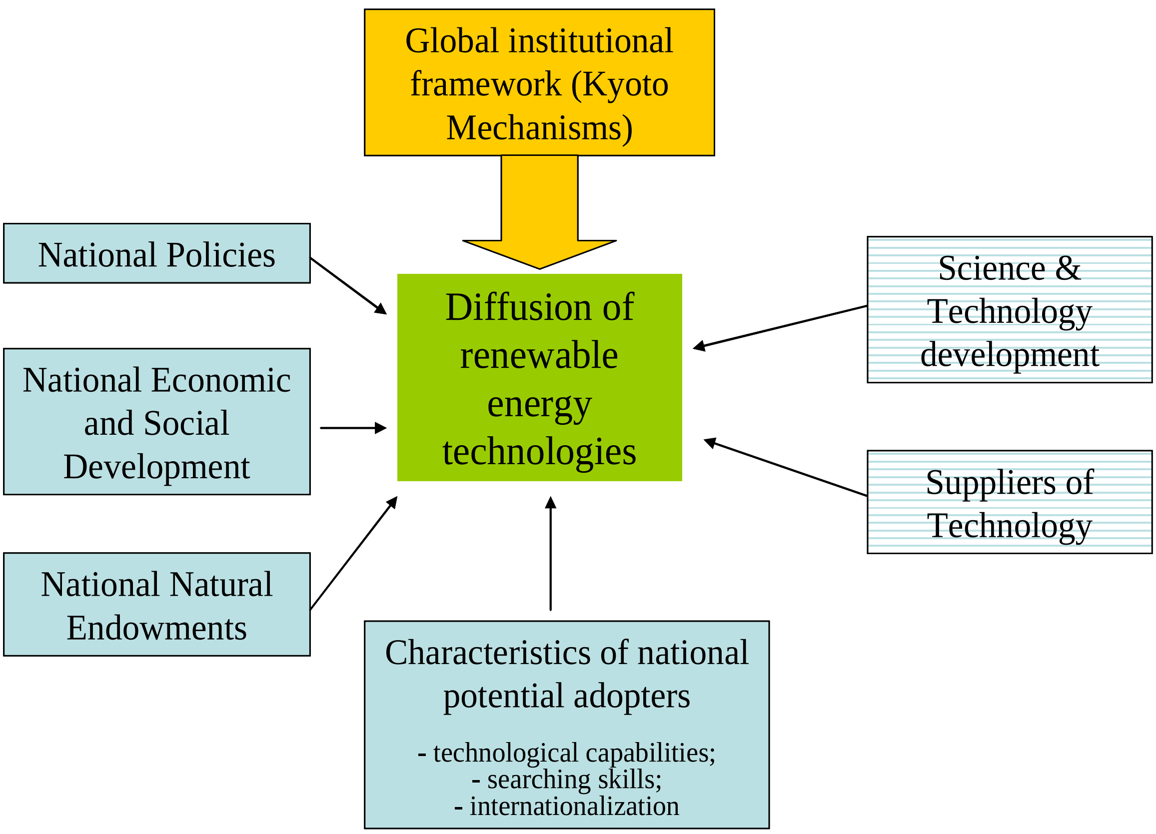
The paper is organised as follows. Section 2 proposes the analytical framework and its operationalization to examine the role of the Kyoto protocol on the diffusion of renewable energy technologies in the BRICS. Section 3 examines the diffusion patterns of renewable energy technologies in the BRICS, contrasting them with the patterns in developed countries. Section 4 provides the results of the empirical analysis to try to explain the diffusion patterns found in the BRICS and examine the role of the different types of incentives created by the Kyoto mechanisms. Section 5 discusses the results and Section 6 concludes the paper.

2. Analytical framework and operationalization

2.1. Analytical framework: the diffusion of renewable energy technologies in emerging economies

We understand diffusion, based on Rogers (1995:5), as the process involved in the transmission of new technological knowledge via given communication and commercialization channels, through time, among the actors in a socio-economic system. The diffusion of new and more sustainable technologies may lead to the (at least partial) replacement of less sustainable variants. Diffusion rates and patterns are affected by several factors (Rogers, 1995; Geroski, 2000).[1] Figure 1 – following a clockwise order – depicts the main factors identified in the innovation diffusion literature as affecting the level and pattern of the spread of new renewable energy technologies.

Figure 1. The factors affecting the diffusion of renewable technologies



For the purposes of our analysis, we consider science and technology developments, and the characteristics of technology suppliers as exogenous dimensions. This is because the science and technology knowledge predominantly used for renewable technology is defined at world level and the influence of individual countries is quite limited.

Characteristics of national potential adopters

The decision to adopt an innovation depends on the benefits users expect from its adoption and the expected costs related to the search for information and eventual mastery of the innovation. The different characteristics of individuals, organizations and countries often influence potential adopters' cost-benefit calculations related to a new technology and, consequently, their decision to adopt it or not (Dieperink et al., 2004; Geroski, 2000). The higher the capability and capacity of potential adopters to search and evaluate the relevant technological information, the higher and the earlier will be their exposure to information on new technologies. Also, the more internationalized their national business activities, the more they will be exposed to mimetic adoption of a managerial culture that is concerned about environmental protection (Abrahamson and Rosenkopf, 1993; Nelson et al., 2004). Also, the technological capabilities of potential national users (including national energy companies) and producers to develop, imitate and adapt international technologies will influence the relative costs and benefits of investment in and adoption of a new technology and its extent of diffusion (Geroski, 2000; Egmond et al., 2006).

National natural endowments

The characteristics of the national natural endowment may influence the expectations of potential users about the costs and benefits of adopting a new technology. The decisions of energy producing firms and/or governments to invest or not in wind, solar or hydro-electric power sources seems to depend on their territories' natural endowments (Kuchler, 2010). The returns from using existing energy sources (e.g. fossil fuels) may discourage a change to renewable energy technologies. Hence, availability (easiness and stability of access) of specific abundant and cheap natural resources may moderate/accelerate the speed of adoption of some renewable technologies.

National economic and social development

The level of a country's economic and social development of countries, which affect the level of environmental awareness, is another influence on the decision to adopt new energy production technologies. The more economically and industrially developed countries will produce more emissions, but its population and policymakers will be more aware of the environmental impact of new energy producing activities (Aden et al., 1999).

National policies

The national institutional framework, in general, and public policies, in particular, can support innovation diffusion by simultaneous promotion of demand and supply of renewable energy technologies. Policies to support the provision and dissemination of information about new technologies and subsidies to encourage their adoption in the socio-economic system will affect users' evaluations of the costs and benefits of innovation adoption, encourage the building of appropriate human capital and stimulate the emergence of innovative inputs markets and new technologies (Hall and Khan, 2003; Justman and Teubal, 1996; Teubal and Andersen, 2000).

Global institutional frameworks (the Kyoto mechanisms)

The Kyoto Protocol and its mechanisms –JI, CDM and the Carbon Trading Scheme – have created a framework, based on market mechanisms and collaboration among the stakeholders in different countries, to support the goal of signatory countries to reduce emissions. At the same time these mechanisms have created incentives for the transfer to, and adoption and diffusion of low carbon technologies in developing and transition countries, to reduce their emissions. The United Nations Framework Convention on Climate

Change (UNFCCC, 2010) states that the Kyoto Mechanisms are expected ‘to stimulate sustainable development through technology transfer and investment…in techniques that can help increase resilience to the impacts of climate change’. It can be expected that tradeable permit regimes will provide incentives for firms to implement cost-effective actions to reduce emissions by rewarding the adoption of environmentally sound technologies to cut emissions, with tradeable carbon credits (UNFCCC, 2010).

The emissions certification procedures in JI and CDM projects are similar, but are based on different eligibility criteria. The CDM allows industrialized countries’ governments or private organizations with carbon emissions reductions obligations under the UNFCCC (Annex 1 countries), to implement emissions abatement projects in developing countries (non-Annex 1 countries) with no formal commitment within the Kyoto agreement to reduce emissions. Participants in CDM projects can obtain certified emissions reduction (CER) or carbon credits that can be traded and used by the industrialized countries to meet their reduction obligations.

The JI mechanism allows joint conduct of emissions reduction projects by two UNFCCC countries (Annex I states). There are 33 countries (most of the developed countries and a few former USSR states) eligible for participation in JI mechanisms (UNFCCC, 2009). JI projects normally involve Russian and Eastern European sellers of Emission Reduction Units (ERU) to buyers in countries in Western Europe with more stringent emissions reduction obligations (Hepburn, 2007). The JI allows a country to claim credit for emissions reductions arising from investment in other industrialized countries, which results in a transfer of equivalent ERUs between Annex I countries.

Within this international environmental institutional framework, Russia is eligible to host JI projects, and Brazil, China, India and South Africa are allowed to host CDM projects. Thus, the countries comprising BRICS do not have the same status within the Kyoto mechanisms. The CDM and JI mechanisms were implemented gradually following the 2001 Marrakesh Accords, with the first projects beginning in 2004, almost a decade after the Kyoto Protocol was adopted in 1997 (CDM, 2010; UNFCCC, 2009).

2.2. Operationalization of the analytical framework

We examine the role of the Kyoto mechanisms and other factors (see Figure 1) involved in the diffusion of renewable energy technologies in BRICS, in two steps. First, we examine the patterns of diffusion of renewable energy technologies in these countries and contrast them with those in the developed countries, to determine whether the BRICS were lagging in diffusion of renewable technology before implementation of the Kyoto mechanisms in 2004. Second, based on the findings in the literature, we investigate which factors are associated with a high reliance on renewable energy technologies in the BRICS. We focus on the Kyoto protocol mechanisms and analyse the technological scope of the projects hosted by the BRICS under the Kyoto mechanisms, in order to examine the types of incentives these mechanisms have created for diffusion.

2.2.1. Level of diffusion of renewable energy technologies in the BRICS

We examine the patterns of diffusion of renewable energy in the BRICS and contrast them with a group of developed countries, including the main buyers of CER under the Kyoto mechanisms, using data from the World Bank Indicators (WBI) and from Renewable Energy for the 21st century network (REN21) (2007, 2009). We use WBI data to examine the evolution generally, over the period 1987-2006, of the *share of renewable sources in total energy sources*; we then analyse more specifically the evolution of reliance on biomass sources based on *total share of combustible renewables and waste in total energy*. We examine the world ranking of countries in terms of capacity and annual production of modern renewable energy to determine whether the BRICS are lagging or not compared to the developed countries, for use of renewable energy technologies. The data are from REN21 reports (REN21, 2007, 2009).

Finally, given the importance of electricity in the total energy produced and used, we analyse the reliance of BRICS on different energy sources of electric power production using WBI data. We use WBI data on the evolution of share of electricity production using hydro, natural gas, coal and oil, and nuclear power. Note that, since we rely on aggregate data, we cannot differentiate among the levels of sustainability and efficiency of the technologies used. For example, we cannot determine whether national reliance on hydropower is based on mainly small sustainable or large unsustainable sources, or whether reliance on coal reflects the use of efficient or non-efficient coal/oil electricity producing technologies.

2.2.2. The Kyoto mechanisms and other factors influencing the diffusion of renewable energy technologies in the BRICS

Factors associated with the diffusion of renewable energy technologies in the BRICS

To understand the influence of the several different factors identified in the literature, including the Kyoto mechanisms, on the diffusion of renewables in the BRICS, we examine Spearman’s correlation coefficients of the level of diffusion of renewable energy sources and the efficient of use of energy, and proxies for the dimensions of all the factors discussed in Section 3 (Figure 1). Below, we describe the proxies used to measure each dimension. It should be noted that this exercise is informative about the degree of dependence and linear association among the variables, but it cannot inform us about the cause-effect relationships among them. For all the variables except those relating to the Kyoto mechanisms, we use data for 1987-2006 collected from the WBI. For the variables related to the Kyoto mechanisms we use UNFCCC data for 2004-2008.

Diffusion of renewable energy technologies. We use the *share of renewable sources in total energy sources* as a proxy for the level of diffusion of renewable energy technologies. We also use *the percentage of fossil energy in total energy consumption*, which provides information on the reliance on fossil fuels. *Level of GDP per unit of energy use* is used as a proxy for the efficiency of energy technologies and *level of GDP per unit of energy used* proxies for the contribution of energy efficiency from non-renewable energy technology, such as ‘fossil fuel switch’ and ‘efficiency energy supply on the supply side’.

Characteristics of national potential adopters. We account for technological search and internationalization capabilities of national firms. For *national technological capabilities*, we include the shares of high-technology exports, R&D expenses in GDP, and royalties received on GDP, as well as numbers of scientific papers and patents per 1,000 population, and researchers and technicians in R&D, as proxies for national technological capabilities. To account specifically for *search capacity and capabilities*, we include expenditure per student in tertiary education, percentage of computer, communication in services, and secure servers. As additional proxies for *level of internationalization of national business*, we use the shares of ISO-certified firms, FDI in GDP, royalties in GDP paid abroad, and trademarks per 1,000 population split by residents and non-residents.

National natural endowments. Among the national natural inputs expected to provide positive support for the use of renewable energies, we include internal freshwater sources, and area forest in total land area. Among national natural inputs discouraging the use of renewable energy technologies, we consider fuels as a share of exports. We account also for country size, and size and density of its population.

Economic and social development. We include level and rate of growth of GDP per capita, expenditure on health, literacy rate, expenditure per student in primary and secondary education, share of economically-active children, and numbers of daily newspapers, Internet users, personal computers and vehicles per 1,000 population as well as share of GDP in agriculture, industry and services.

National policies.[2] For the purposes of this analysis we include variables for national policy culture and capabilities, i.e. shares of military expenses, natural protected areas, investment in energy as share of GDP, and investments in energy with private parties.

Global institutional framework (Kyoto mechanisms). To account for the level of influence of international institutional frameworks, we include the number of CDM and JI projects and the level of CER and ERU derived from projects hosted in each country, in each year. It would be interesting to include variables related to the technological focus of the projects hosted by the BRICS; unfortunately, these data are available only for 2009, i.e. we have only five observations.

Incentives created by the Kyoto collaborative mechanisms for diffusion of renewable energy technologies in the BRICS

To examine the incentives provided by the Kyoto mechanisms for the diffusion of renewable energy technologies, we assessed the projects hosted by BRICS and specifically their technological scope. Comparing the technological scope of projects with the capabilities of BRICS in these technologies, provides some understanding about whether the Kyoto mechanisms support the diffusion of specific renewable technologies across all host countries or if host countries are chosen based on the possibility of cheap CER relying on the host country' existing endogenous capabilities. In other words, if countries attract CDM or JI projects in technological areas where they have installed technology capacity and capabilities, then the value of Kyoto mechanisms to support the diffusion of new renewable technologies towards the emerging economies are likely to be limited and instead may only be encouraging the expansion of existing capacity.

For our investigation, we use UNFCCC data on number and budgets of CDM and JI projects hosted by BRICS and the technology focus of these projects. The data are analysed using descriptive statistics methods, including revealed advantage ratios.

3. Diffusion patterns of renewable energy technologies in BRICS countries

Table 1 presents the share of renewable sources in total energy sources. In 2006, Brazil shows high reliance on renewable sources of energy (48%), followed by India (39%) and China (15%). Compared to the developed countries, Brazil and India are among the countries with the highest use of renewable sources, although they are ranked lower than

Austria (69%). Despite lower use of renewable sources, China, South Africa and Russia respectively are comparable to Germany, Denmark and the UK. These data underline the heterogeneity in the intensity and patterns of renewable energy use in both the BRICS and the developed countries. The major difference between the BRICS and the developed countries is that reliance on renewable energy sources refers to the evolution of diffusion of these renewable sources. During the 1990s and early 2000s, the reliance on renewable energy sources in the BRICS was maintained or decreased, while in the group of developed countries analysed intensity increased or was maintained.

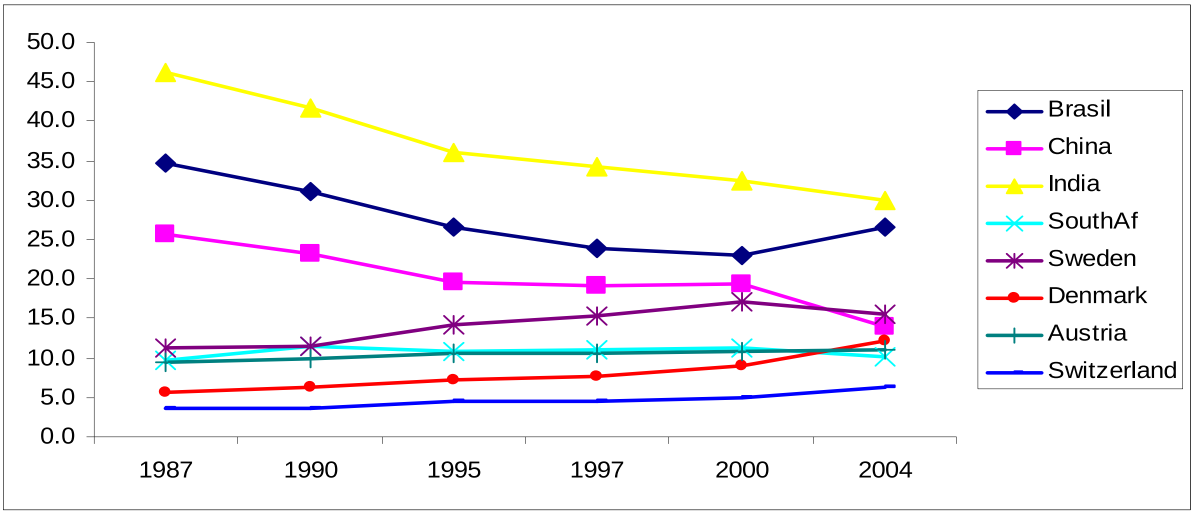
Table 1. Share of renewable sources in total energy sources in the BRICS countries and a group of developed countries

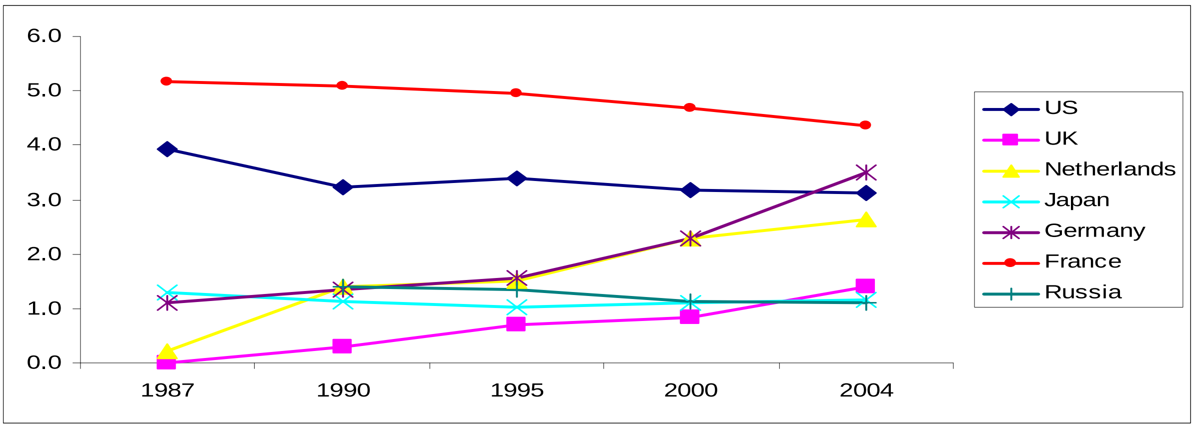
	1990	1995	1997	2000	2004	2006
Brazil	63%	61%	58%	49%	49%	48%
China	24%	21%	21%	22%	17%	15%
India	48%	44%	42%	43%	40%	39%
Russia	2%	2%	2%	2%	2%	2%
South Afr.	9%	9%	9%	9%	9%	9%
Austria	61%	67%	68%	68%	67%	69%
Sweden	39%	40%	42%	48%	38%	44%
Switzerland	33%	36%	35%	35%	35%	34%
France	14%	14%	13%	13%	12%	12%
Denmark	11%	9%	8%	7%	8%	9%
United States	6%	6%	6%	6%	6%	7%
Germany	3%	4%	5%	7%	11%	15%
Netherlands	1%	1%	2%	2%	2%	3%
UK	0%	1%	1%	1%	1%	2%

Source: International Energy Agency (2009) IEA Scoreboard 2009

We now explore biomass. Graph 1 shows the share of combustible renewables and waste in solid biomass, liquid biomass, biogas, industrial waste and municipal waste, in total energy use in the BRICS and in a group of developed countries, during the period 1987-2004.

Graph 1: Share of combustible renewables and waste on total energy, in the BRICS and some developed countries, 1987 to 2004





Source: World Bank Indicators. Note: Combustible renewables and waste comprise solid biomass, liquid biomass, biogas, industrial waste, and municipal waste, measured as a percentage of total energy use.

In the period analysed, India, Brazil and China show the highest levels of use of renewable combustibles – higher than the developed countries, while Russia has the lowest level. India has the highest level of use of combustible renewables and waste in total energy, despite experiencing a major decrease in these levels. In the 1990s, around 40% of total energy use in India was renewable combustible; in the 2000s this ratio decreased to 30%. This high share seems due to India's reliance on non-commercial energy sources in rural areas, including wood, crop residues and animal waste, whereas the decrease in the use of renewable combustibles would seem attributable to the replacement of traditional sources by more efficient commercial energy sources (India Energy Portal, 2010; KPMG, 2007). Similarly, in the 1990s, 30% and 20% of the energy used in Brazil and China respectively was renewable combustible; in the 2000s it was about 25% in Brazil and 13% in China. The decrease in the use of renewable combustibles in India, China and Brazil may indicate that economic development initially leads to reduced use of traditional renewables and increased use of fossil fuels, rather than an increase in the use of modern renewables (Arnold et al., 2006; Goldemberg and Coelho, 2004; van der Horst and Hovorka, 2009). In Russia and South Africa, on the other hand, the levels of renewable combustibles in total energy consumption were stable and significantly lower during the same period, by about 1% and 10% respectively.

Modern biomass technologies are used as a commercial sources of energy and include transportation fuels (i.e. biofuels, biodiesels, biogasoline combustibles), electricity generation and heat production from agricultural inputs, forest residues and solid waste (Demirbas, 2009; Goldemberg and Coelho, 2004). These modern renewable combustibles have been produced and used in Brazil since the 1970s (Lemos, 2007). According to the International Energy Agency (IEA) figures, in 1990, biofuels, biodiesels and biogasoline combustibles represented 10% of total energy production in Brazil; in 2000-2004 their production decreased significantly, reaching only 5% of energy production in 2004. In 2004-2006 it increased to 6% of total energy. China started production of these combustibles in 2001 (IEA, 2009). The remaining BRICS do not produce any of these combustibles, while in some developed countries they represent 0.1% of total energy sources (IEA, 2009). Thus, in

Brazil, the large, but decreasing (less so than in India or China, though) use of renewable combustibles was also certainly due to modern commercial renewables.

We examine data on the world leaders in existing modern renewable energy capacity and production for 2006 and 2008. Table 2 provides information extracted from the REN21 (2007, 2009), on the five top countries for capacity and annual production of renewable energy.

Table 2. Ranking of the world leaders in existing Renewable energy capacity and production in 2006 and 2008

TOP FIVE COUNTRIES					
2006 **2008**					
	1	**2**	**3**	**4**	**5**
Existing capacity					
Renewables power capacity	China China	Germany United States	United States Germany	Spain Spain	India India
Small hydro	China China	Japan Japan	United States United States	Italy Italy	Brazil Brazil
Wind power	Germany United States	Spain/ United States Germany	Spain/ United States Spain	India China	Denmark India
Biomass power	United States United States	Brazil Brazil	Philippines Philippines	Germany/ Sweden/Finland Germany/Sweden /Finland	
Geothermal power	United States United States	Philippines Philippines	Mexico Indonesia	Indonesia / Italy Mexico	Indonesia / Italy Italy
Solar PV (grid-connected)	Germany Germany	Japan Spain	United States Japan	Spain United States	Netherlands/ Italy South Korea
Solar hot water	China China	Turkey Turkey	Germany Germany	Japan Japan	Israel Israel
Annual production					
Ethanol production	United States United States	Brazil Brazil	China China	Germany France	Spain Canada
Biodiesel	Germany	United States	France	Italy	Czech Republic

production	Germany	United States	France	Argentina	Brazil

Source: REN21 (2007, 2009)

These data show that three of the BRICS are among the five top countries for energy capacity produced from different modern renewable sources. The main difference between developed countries and the BRICS for installed capacity based on modern renewables refers to the primacy of developed countries in establishing the capacity to use solar photovoltaic (PV) sources (grid-connected). Both developed and developing countries are involved in the production of first generation biofuels, not produced using sustainable processes and unlikely to promote sustainable development (de Gorter and Just, 2009; Demirbas, 2009; Ewing and Msangi, 2009, Kuchler, 2010). Some authors point out the biofuel blending authorized in several countries, including Brazil, those in Europe and the US, encourage rather than discourage the use of fossil fuels by lowering the price of blended gasoline and ethanol (de Gorter and Just, 2009; Ewing and Msangi, 2009).

Finally, to investigate the importance of electricity in total energy used and produced, we examine the different sources of energy on which countries rely for electricity production (see Bodas Freitas et al., 2010). According to the WBI, in 2005, natural gas was the main input for electricity production in Russia (45%), and coal was the main input for electricity production in South Africa (90%), China (80%) and India (70%), while hydropower was important in Brazil (82%). Similar differences for reliance on renewable sources for electricity production occur in the industrialized countries. The main difference between the BRICS and the developed countries for energy sources for electricity production is the latter's reliance on nuclear energy, whose use is (still) low in the BRICS. This suggests that the national portfolios of energy producing technologies may be related inherently to their national natural endowments and technological capabilities.

Overall, this analysis suggests that there is heterogeneity among the BRICS as well as with the developed countries in terms of reliance on different energy sources, and the composition of and extension to their portfolios of renewable energy sources. Although, the intensity of reliance on renewable sources is uneven across countries, there is not a huge divide between the BRICS and the group of developed countries analysed. In 2006, Brazil and India were among the countries with highest level of reliance on renewable sources. However, there are differences in the pattern of diffusion of renewable sources since the early 1990s, with decreased reliance in most BRICS on renewable sources and increased reliance in most of the developed countries, most likely reflecting reduced use of traditional renewables in the BRICS and increased use of modern renewables in developed countries.

National portfolios of renewable technologies also vary. For example, modern biofuels were especially important in Brazil, but, in the late 2000s, Germany and the US became leaders for the production of biofuels. Biofuels are increasingly important in China; wind power is important in India and China; and small hydro is increasing in importance in China and Brazil. The major difference between the BRICS and the developed countries seems to be related to the use of solar PV technology, which is higher in the advanced countries.

4. Explanation for the diffusion patterns identified

4.1. Factors supporting the diffusion of renewable energy technologies in the BRICS

We test for linear associations between the economic, social, technological and policy characteristics of BRICS, their level of attraction of projects under the Kyoto mechanisms, and their levels of diffusion of renewable energy technologies and energy efficiency. Table 3 provides a summary of the Spearman's correlation analysis performed on data for 1987-2006 for the BRICS. Correlation coefficients for Global institutional frameworks (Kyoto mechanisms) are performed for the last three years in the time series, which are the only available observations.

Table 3. Summary of correlation analysis of the groups of factors affecting the diffusion of renewable energy technologies in BRICS: 1987 to 2006

			% Renewable sources on total energy sources	% Fossil fuel energy consumption on total	GDP per unit of energy use (PPP $ per kg of oil equivalent)
Characteristics of national potential adopters	Internationalization of national business	FDI, ISO certification			
		Export as import capacity; Royalties paid abroad % GDP	-	+	
		Trademarks non residents		+	
		Trademarks residents			+
	National technological capabilities	High-technology exports; R&D expenditures as % GDP; Patents residents per 1000 population; Researchers and technicians in R&D; Royalties received as % of GDP; Scientific papers per 1000 population	-	+	-
	National search capabilities	Expenses per student in tertiary education	+		
		% of Computer, communications on services Secure servers	+	-	+
National natural endowments		Fossil resources	-	+	-
		Population (size and density)	+	-	
		Water resources		-	
		Forest resources	+		
National economic and social development		Literacy, Expenses per student, Health expenditures	-		-
		GDP per capita	-	+	-
		Vehicles and computers	-	+	
		Government debt			+
		Growth GDP per capita			
		GDP industry	-	+	-
		GDP agriculture	+	-	-
		GDP services; Daily newspapers,			

		Internet users, Children economically-active			
National policies	National policy culture	Investment in energy with privates % GDP	+	-	+
		Investment in energy % GDP	-		
		% National protected areas			
		Military expenditures % GDP	-	+	-
Global institutional frameworks (Kyoto mechanisms)		Number of CDM and JI projects*		-	+
		CER registered*			

* 13 to 15 observations rather than 85 to 90 observations as for the other variables.

The results suggest that the capabilities of potential national adopters are associated with the level of diffusion of renewable technologies and the efficient use of energy. The degree of internationalization of national business activities has perhaps not favoured the development of a more environmentally friendly managerial attitude in the BRICS, suggesting that environmental concerns are not high on the agendas of management in the global business environment. The national technological capabilities of BRICS, measured by high-technology exports, R&D expenditure and royalties as a percentage of GDP, patents and scientific papers per thousand population, are negatively associated with the development of sustainable technologies, but positively correlated with reliance on fossil fuels. These results suggest that most of the BRICS national R&D activities are focused on advances in energy-intensive industries/technologies. Search skills and capacity for technology diffusion seem to be positively associated with diffusion of renewable energy sources; the level of national investment in higher education, percentage of computer and communications in services and secure servers seem to enhance the diffusion of renewable technologies.

The results suggest that national natural endowments have created different incentives for the use of specific energy technologies. National endowments in fossil fuels are associated with higher levels of emissions and lower levels of adoption of renewable energy technologies; endowments in internal freshwater and forest resources have the opposite effect. Size and density of the national population is positively correlated with diffusion of renewable energy sources. Also, in the BRICS countries, economic development and industrialization have relied on fossil-based technologies. The share of industry activities in the national product, level of GDP per capita, and number of computers and vehicles are positively associated with the share of fossil fuels in total energy consumption.

In economies where investments in energy are made in cooperation with private partners, the diffusion of renewable energy technologies may be more rapid than in military and energy focused economies, where attention tends to be diverted from environmental concerns. This would seem to be confirmed by the negative and significant correlation coefficient of level of renewable in total energy sources and its positive and significant correlation coefficient of level of fossil fuels in total consumption.

Finally, despite the short time series available for examination of these linear associations, our results indicate that the numbers of CDM and JI projects are positively correlated with increased output per unit of energy use and, consequently, to more efficient economic use of fuel energy. The number of CDM and JI projects, however, is not associated with the use of renewable sources of energy. The correlation coefficient of the variable CER of registered CDM projects is not significant.

4.2. Role of the Kyoto collaborative mechanisms in creating incentives for diffusion

4.2.1. The number of JI and CDM projects in the BRICS Countries

Table 4 summarizes the number of JI and CDM projects implemented, validated or still to be validated, which are hosted by each of the BRICS countries. In 2004 to 2007, India and Brazil attracted a higher number of CDM projects. After 2007 China became the most attractive destination, and by 2009, and accounted for more than half of total registered or in-the-pipeline CDM projects, in terms of number of projects and CER (UNFCCC, 2009). South Africa is ranked fairly low for countries benefiting from CER (UNFCCC, 2009).

Table 4. Numbers of CDM and JI projects in BRICS

	2004	**2005**	**2006**	**2007**	**2008**	**2009***	**Total**
Brazil	18	86	79	62	100	16	361
China	2	25	221	680	667	171	1766
India	11	198	268	304	375	95	1251
South Africa	1	6	9	7	4	2	29
Russia			12	43	37	7	99
Total CDM	60	473	837	1409	1561	393	4733
Total JI			23	84	84	13	204

* May 2009; Note: CER- certified emissions reduction

In May 2009, there were 204 JI projects in the pipeline: 102 (48%) in Russia, 34 (16%) in Ukraine, 59 (28%) in other Eastern European countries, 7 (3%) in Germany, 6 (3%) in New Zealand, and 1 in France (CDM, 2009). While 48% of JI projects have been implemented in Russia, 61% of the emissions reductions forecast for 2012 resulting from all JI projects, are expected to benefit Russia.

In May 2009, there were 4,733 CDM projects in the pipeline. Of these, 2,935 were in the process of validation, 1,596 were registered (500 already had issuance of CER), and 202 were in the registration process stage. Sixty per cent of these CDM projects are aimed at reducing carbon dioxide emission by between 10Kt and 100Kt per year; 25% are aimed at reductions of 100Kt to 500Kt per year, and 10% are aimed at reductions of less than 10Kt per year. Almost 80% of CDM projects are hosted by Asian countries, 18% by Latin American countries and 2% are in African countries. The BRICS countries attract the majority of CDM and JI projects. As of May 2009, 70% of world CDM projects and 49% of JI were located in BRICS countries.

We turn next to the major buyers of the CDM and JI projects hosted in 2009 by BRICS countries (Table 5). The major buyers of JI projects, in rank order, are the Netherlands, the UK, by Austria, Denmark and Japan. These five countries account for more than half of the JI projects hosted by BRICS (JI, 2009). Among JI projects hosted by Russia, 25% were bought by the UK, 9% by Denmark, 5% by Austria, 5% by the Netherlands and 4% by Sweden, the remainder going to national and international organizations (e.g. World Bank).

Table 5. Main buyers of CDM and JI projects in pipeline hosted by BRICS: 2009

	CDM projects				JI projects
	Brazil	China	India*	South Africa	Russia
Austria	0%	3%	0.40%	0%	6%
Denmark	0%	1%	0%	4%	9%
Germany	2%	6%	3%	4%	0%
Japan	7%	15%	2%	4%	2%
Sweden	1.4%	10%	0.40%	0%	4%
Switzerland	21%	11%	6%	7%	2%
The Netherlands	10%	15%	2%	18%	5%
United Kingdom	28%	33%	13%	29%	25%
Share of total projects bought by these 8 countries	69%	94%	27%	66%	53%

Source: UNFCC (2009), CDM (2009), JI (2009).

Note: In India, 75% of projects were proposed by international or national organisations.

The major buyers of CDM projects are the UK, Switzerland, the Netherlands and Japan, which account for around 66% of the projects in Brazil, 53% of the projects hosted by South Africa and China, and 23% of projects hosted by India. Since about three-quarters of the Indian projects were proposed by international or national organizations, this group of buyers is responsible for almost all the projects promoted by private or public organizations from developed countries. Germany and Sweden are important buyers (16%) of the projects hosted in China. Switzerland is the only country in Europe with no individual involvement in projects in China.

4.2.2. Technological scope of JI and CDM projects in the BRICS

Table 6 provides details on the technological scope of all JI projects in the pipeline and the JI projects hosted in Russia. We find one main difference in their technological and sectoral scope: projects hosted in Russia mostly address energy efficiency in manufacturing rather than in the supply.

Table 6. Technological and sectoral scope of all JI projects and those hosted in Russia, May 2009

	% total JI projects	**% total CER**	**% JI projects hosted in Russia**
Fugitive	33%	46%	**33%**
EE (efficiency energy) supply side	11%	6%	2%
Biomass energy	10%	2%	**10%**
Fossil fuel switch	10%	5%	**10%**
Landfill gas	8%	5%	**8%**
N2O	7%	16%	**7%**
Energy distribution	5%	1%	5%
Hydro	4%	1%	4%
HFCs	3%	3%	3%

EE industry	2%	2%	**11%**
Coal bed/mine methane	2%	11%	2%
Biogas	1%	0%	1%
Cement	1%	1%	1%
CO2 capture	1%	1%	1%
PFCs	1%	1%	1%
Total number of projects	204		99

Source: UNFCC (2009), JI (2009)

Columns 1-4 in Table 7 provide information on the sectoral and technological scope of CDM projects in the pipeline in Brazil, China, India and South Africa; columns 5-7 provide details of all CDM projects issued, registered and in the pipeline, regardless of the host country.

Table 7. Sectoral and technological scope of CDM projects, issued, registered and in the pipeline in Brazil, China, India and South Africa, in May 2009

	Brazil	**China**	**India**	**South Africa**	**World**		
	pipeline	**pipeline**	**pipeline**	**pipeline**	**issued**	**registered**	**Pipeline**
Hydro	21%	**47%**	**10%**	**7%**	19%	25%	27%
Biomass energy	**32%**	4%	27%	14%	21%	16%	15%
Wind	**3%**	19%	24%	**0%**	18%	14%	15%
EE own generation	3%	15%	10%	3%	6%	7%	9%
Landfill gas	11%	3%	2%	**21%**	7%	8%	8%
Biogas	2%	2%	3%	**10%**	1%	6%	6%
Agriculture	**16%**	0%	0%	0%	8%	8%	5%
EE industry	1%	1%	12%	3%	4%	3%	4%
Fossil fuel switch	5%	2%	4%	**14%**	4%	2%	3%
N2O	1%	2%	0%	**14%**	2%	3%	1%
Coal bed/mine methane	0%	4%	0%	7%	1%	1%	1%
EE supply side	1%	1%	2%	0%	1%	1%	1%

Cement	0%	0%	2%	0%	1%	1%	1%
Reforestation	1%	0%	1%	0%	0%	0%	1%
Fugitive	1%	0%	1%	3%	1%	1%	1%
Solar	0%	0%	0%	0%	0%	1%	1%
Other scopes representing less than 1% of world projects	2%	1%	2%	3%	5%	3%	2%
Total number of projects	361	1766	1251	29	500	**1596**	**4733**

Source: UNFCC (2009), CDM (2009)

We examined the technological scope of CDM projects hosted by the BRICS and compared with the profile of CDM projects. We found some national specificities:

- Projects hosted in Brazil concentrate on biomass, hydropower, energy efficiency in agriculture, and landfill gas. Brazil has a large relative advantage in attracting CDM projects in agriculture efficiency and biomass, and a large relative disadvantage in CDM on wind technologies, compared to total CDM projects in the pipeline.
- Projects hosted in China focus mainly on hydropower, wind, energy efficiency of energy production and coal mining. China has a greater relative advantage in attracting projects related to coal mining, and some advantages in hydropower and energy efficiency of energy production. It has a great relative disadvantage in CDM projects in biomass and agriculture efficiency, compared to total CDM projects in the pipeline.
- Projects hosted by India focus on biomass, wind, energy efficiency in industry (especially the cement sector), and efficiency of energy production. India's relative advantages are in energy efficiency of energy production, and to some extent, in CDM projects on biomass and wind technologies. India has a relative disadvantage in energy efficiency in agriculture, hydropower and landfill gas.

- Projects hosted by South Africa focus on landfill gas, biogas, N_2O and fuel switching. South Africa has a greater relative advantage in attracting projects on coal mining, fuel switching, and landfill gas, i.e. projects in areas where there are very few CDM projects. Since South Africa hosts fewer projects than the other BRICS, its percentages and relative advantage ratios are larger.

The analysis of the technological scope of projects by buyer country suggests that the participation of buyers in specific technologies differs according to the host country. In other words, buyers do not specialize in projects with a specific technological scope (for details, see Bodas Freitas et al., 2010). However, this result requires further investigation using different data because the buyers and the technology providers of CDM and JI projects may not be the same.

Overall, this analysis reveals that JI and CDM projects, with the exception of biomass and landfill gas, have different technological focuses. Eighty per cent of JI projects focus on rogue emissions from fuels, energy efficiency on the supply side, biomass energy, fossil fuel switching, landfill gas and N_2O; 80% of CDM projects focus on hydro energy, biomass energy, wind, energy efficiency own generation, landfill gas, biogas, agriculture, and energy efficiency in industry. Also, the technological focus of hosted projects varies across the BRICS, with a bias among CDM projects on technological areas in which host countries already have considerable production capacity and locally available and widely diffused technologies (see Section 5.1). Solar technologies represent less than 1% of total CDM projects in BRICS.

5. Discussion

Our analysis suggests that there is a huge heterogeneity across the BRICS in the intensity and composition of use of renewable sources for energy production. These countries are not lagging behind the developed countries for reliance on renewable sources and are embracing modern renewable energy sources such as biofuels and wind energy. The major difference between the developed and developing countries is in reliance on solar PV technologies which are much more diffused in the developed countries, but there are also differences in the evolution of the use of renewable sources. Since the early 1990s, reliance on renewable sources of energy has generally decreased in the BRICS, reflecting reduced use of traditional renewables such as firewood, crop residues and animal waste; in the developed countries reliance on renewable energy has increased as the result of investment in modern and more sustainable renewable technologies.

Despite the stated objective of the Kyoto mechanisms to increase the diffusion of technologies to support sustainable development in developing and emerging countries, CDM and JI projects are concentrated in a few countries. More than 70% of CDM projects are hosted by the BRICS countries, with China accounting for almost 50% of total projects. There is similar inequality in relation to the buyers of JI and CDM projects with Japan, the Netherlands, Switzerland and the UK accounting for more than 50% of investment in CDM projects in the BRICS countries.

There are national differences in the attraction of CDM and JI projects based on technological scope. The majority of national projects involves the use of mature technologies already diffused locally, including technologies that may represent less sustainable variants of renewable energy technologies compared to alternatives available in the international market. Most projects hosted by Brazil employ biomass energy and hydropower technologies; hydropower and wind technologies are dominant in China; biomass and wind energy technologies in India; and energy efficiency technologies in manufacturing in Russia. These findings confirm earlier observations that the CDM mechanism in particular, focuses on the use of locally available technologies and capabilities (Dechezlepretre et al., 2008; Doranova, 2009).

Our results show also that the diffusion of renewable technologies is positively associated with national natural endowments, national search capacity, and national policy culture, and negatively associated with national economic and social development. For instance, Russia's fossil fuel endowment and national policy of investing heavily in the military probably creates low levels of incentives for projects on renewables. Brazil's abundant natural resources — water, forests and agriculture — result in higher diffusion of renewable energies based on hydropower and biomass. Emerging Asia, represented by China and India, is a region of high economic growth and rapid industrialization in manufacturing, resulting in increased consumption of energy, particularly fossil fuel based energy, following an inverted Environmental Kuznets curve (e.g. O'Conner, 1996). In these countries increase in the indicators for national economic and social development has been accompanied by an increased share of fuel based energy use. Thus, the number of CDM projects seems to be positively associated with efficient use of fossil fuels.

These results raise interesting questions about the role of the Kyoto mechanisms on the diffusion of renewable energy technologies. First, to what extent are the Kyoto mechanisms supporting the diffusion of more sustainable and dynamic renewable energy technologies to promote sustainable development? Our analysis shows that the CDM and JI projects generally exploit already widely used technologies in host countries and often less sustainable variants of renewable energy technologies. Locally available technologies and associated know-how allow buyers to undertake low opportunity-cost ('low hanging fruit') projects that can be implemented quickly and allow investors in both developed and emerging countries to acquire low cost emissions units and profit from trading CER. In the context, the Kyoto mechanisms are providing perverse incentives because emission cuts stemming from low opportunity cost projects are priced the same as those stemming from more complex costly projects, and involve less burdensome bureaucracy. The former usually involve local, less sophisticated technologies, such as first generation biofuels, conventional biomass, and hydropower, which are widespread locally and which are still linked to environmental unsustainability[3] or the adoption of new equipment (hardware transfers). Thus, most CDM projects are failing to have a substantial impact on the diffusion of comparatively more sustainable variants of renewable technologies such as solar cells, wind power, second generation biofuels, etc. These observations are confirmed by empirical evidence, which demonstrate that most CDM projects rely on local technologies, with less than 20% exploiting foreign technologies (Dechezlepretre et al., 2008; Doranova, 2009). CDM projects may be reinforcing patterns of specialization in the emerging countries in low variants technological paths, such as first generation biofuels in Brazil and large hydro in China. The Kyoto mechanisms may be promoting lock-in in developing and transition countries to technologies promoting environmental unsustainability.

Second, based on empirical observations, we would question the role of endogenous technological capabilities and efforts to shape the incentives for technology diffusion and the impact of CDM and JI projects. BRICS countries seem to attract projects in sectors and technologies where they have considerable production capacity and technological capabilities, which is signalling the potential availability of cheap and easy carbon credits.

For instance, Brazil tends to attract biomass projects, while India, and to a lesser extent China, attract wind energy projects. All these countries are among the world leaders for production of energy based on these respective sources (Lemos, 2007; Lewis and Wiser, 2007, REN21,2007, 2009). These observations suggest that national technological efforts and capabilities may be important factors for attracting CDM projects and creating incentives for further technology diffusion. Overall, industrial technological development is accompanied by economic development, which may lead to higher demand for fossil fuels (Arnold et al., 2006; van der Horst and Hovorka, 2009). The development of capabilities in specific renewable technologies would allow these countries to signal to carbon markets the potential for relatively cheaper CERs through reliance on local capabilities and infrastructure (eventually ongoing projects). In contrast to CDM projects on sewage and landfill, those on wind, hydro and biomass projects seem to be tightly connected to host country characteristics (Schneider et al., 2010).

Third, there is a question about the extent to which the creation of additional incentives for the diffusion of renewable energy in emerging economies may depend on existing national policies and national implementation of the Kyoto Mechanisms. Countries' policy objectives vary and different policy instruments are employed to implement international agreements. This diversity can lead to considerable variation in the functioning of new market-based incentives and in their outcomes. Since CDM projects require national government approval, their implementation will be influenced by national policy. Some countries, such as China (75% of projects) and South Korea (88% of projects), impose a requirement for technology transfer (Popp, 2008).[4] India and Brazil do not have this requirement and the percentage of CDM projects that include technology transfer is much smaller (Popp, 2008). China's good performance in attracting and benefiting from CDM projects may reflect national government efforts to focus CDM support on national priorities (by adding its own national requirements). There is a parallel in the way Ireland exploited the European Structural Funds in its favour (Barry, 2000; Sharp, 1998) and how China seems to derive advantage from CDM projects (in contrast to other countries, such as, South Africa) (Fay et al., 2010; Schroeder, 2009). Also, different national environmental policies (e.g. environmental taxes, investment tax incentives, tradeable permits, user charges, deposit refund systems) contribute to the non-functioning of the carbon market created by the Kyoto mechanisms. Not all countries implemented marketable permits to regulate national environmental issues.

6. Conclusions

This study analysed whether the Kyoto mechanisms have encouraged the diffusion of renewable energy technologies in the BRICS countries i.e. Brazil, China, India, Russia and South Africa. We addressed the issue by considering the extent to which these technologies were already diffused in these countries, the incentives that the Kyoto mechanisms created for their diffusion, and the factors that influence the level of use of renewable energy technologies in the countries analysed. We relied on national aggregate data from the WDI, the IEA and the UNFCCC, and studies in the literature.

Our results suggest that there is great heterogeneity across the BRICS in the intensity and composition of their use of renewable sources of energy. They do not appear to be lagging behind the developed countries for reliance on renewable sources. In relation to the incentives for diffusion associated with the Kyoto mechanisms, we identified national specialization as an attractant for projects with specific technological scope, and a focus on locally diffused mature technologies, even when they represent less sustainable variants of renewable energy technologies compared to the alternatives in the international market.

National efforts to encourage the use of new technology and install capacity seem to determine the nature of incentives for technology diffusion and the benefit of projects implemented under the Kyoto mechanisms. The Kyoto mechanisms are associated with efficiency of use of fossil fuels, but not renewable energies, which instead is positively associated with national natural endowments, higher education, search capacity and national policy culture.

Our analysis suggests that the Kyoto mechanisms are not creating incentives for the use sustainable variants of renewable energy technologies in the BRICS countries; they are merely encouraging increased installed capacity of existing technologies. Consequently, they are likely to reinforce traditional technology trajectories, which will make it more difficult to develop more environmentally sustainable growth paths. These market-based incentives, on their own, are likely to lead to inefficient and non-sustainable energy systems (especially those based on some sources of biomass), and to increased economic and resource inequalities across countries (Kuchler, 2010).

Our study has some limitations, mostly related to its reliance on macro aggregated and secondary sources of data which do not allow us to examine differences in the levels of sustainability of energy producing technologies based on renewable sources. Lack of time-series data on the number and technological focus of CDM and JI projects prevented us from examining how the technological focus of projects undertaken under CDM or JI arrangements relate to the national characteristics of BRICS, and to conduct econometric investigation of the influence of national characteristics, including attraction of Kyoto collaborative projects, on the level of diffusion of renewable technologies.

To examine the influence of the Kyoto mechanisms on diffusion, we need a better understanding of CDM and JI, their implementation, negotiation of objectives among participants, and the critical elements/requirements attracting buyers to invest in projects. Further research is needed to understand whether projects are private buyer or government driven and whether and how CDM host countries put institutional and corporate efforts into attracting and negotiating these projects. Analysis of these issues requires the collection of project level data and interviews with project participants.

Acknowledgments

The authors acknowledge comments and suggestions from Professor Ed Steinmueller and two anonymous referees. The usual disclaimers apply.

References

Abrahamson, E., Rosenkopf, L., 1993. Institutional and competitive bandwagons: using mathematical modelling as a tool to explore innovation diffusion. Academy of Management Review, 18(3), 487-517.

Aden, J., Hong, A. K., Rock, M., 1999. What is Driving the Pollution Abatement Expenditure Behavior of Manufacturing Plants in Korea?. World Development, 27, 1203-1214.

Arnold J. E. M., Kohlin, G., Persson, R., 2006. Woodfuels, Livelihoods, and Policy Interventions: Changing Perspectives. World Development, 34, 596-611

Barry, F., 2000. Convergence is not Automatic: Lessons from Ireland for Central and Eastern Europe. The World Economy, 23, 1379-1394.

Blackman, A., Sisto, N., 2006. Voluntary Environmental Regulation in Developing Countries: A Mexican Case Study. Natural Resources Journal, 46, 1005-1042.

Bodas Freitas, Isabel, Eva Dantas, Michiko Iizuka, 2010. The global institutional framework and the diffusion of renewable energy technologies in the BRICS countries, UNU-MERIT Working paper no. 045.rnold

CDM, 2009. Clean Development Mechanisms. http://cdm.unfccc.int/Statistics/index.html, retrieved in June 2009.

CDM, 2010. CDM Rule Book. http://cdmrulebook.org/305, retrieved in May 2010.

de Gorter, H., Just, D. R., 2009. The Economics of a Blend Mandate for Biofuels. American Journal of Agricultural Economics, 91, 738-750

Dechezleprêtre, A., Glachant, M., Ménièrea, Y., 2008. The Clean Development Mechanism and the international diffusion of technologies: An empirical study. Energy Policy, 36, 1273-1283.

Demirbas, M. F., 2009. Biorefineries for biofuel upgrading: A critical review. Applied Energy, 86 S151–S161.

Dieperink, C., Brand, I., Vermeulen, W.,2004. Diffusion of energy-saving innovations in industry and the built environment: Dutch studies as inputs for a more integrated analytical framework. Energy Policy, 32, 773–784

Doranova, A., 2009. Technology transfer and learning under the Kyoto Regime: Exploring the technological impact of CDM projects in developing countries. PhD Thesis, UNU-MERIT, Maastricht.

Doranova, A., Costa, I., Duystersa, G., 2010. Knowledge base determinants of technology sourcing in clean development mechanism projects, Energy Policy, 38 (10), 5550-5559

Egmond, C., Jonkers, R., Kok, G., 2006.. One size fits all? Policy instruments should fit the segments of target groups. Energy Policy 34, 3464-3474

Espinola-Arredondo, A., Munoz-Garcia, F., 2009. Free-riding in International Environmental Agreements: A Signaling Approach to Non-Enforceable Treaties. School of Economic Sciences, Washington State University Working Paper Series 2009-08.

Ewing, M., Msangi, S., 2009.. Biofuels production in developing countries: assessing tradeoffs in welfare and food security. Environmental Science & Policy,12, 520 – 528

Fay, J., Kapfudzaruwa, F., Na, L., 2010. A comparative analysis of CDM in South Africa and China Redefining the role of CDM n the quest for putting a price on carbon in South Africa, In Winkler H., Marquard A., and Jooste M. (eds) Putting a price on Carbon. Economic instruments to mitigate climate change in South Africa and other developing countries. Proceedings of the conference held at the University of Cape Town, 23-24 March 2010. p. 106-126.

Geroski, P.A., 2000. Models of technology diffusion. Research Policy, 29, 603-625.

Goldemberg, J., Coelho, S. T., 2004. Renewable energy—traditional biomass vs. modern biomass. Energy Policy 32, 711–714.

Hall, B. H., Khan, B., 2003. Adoption of New Technology. NBER Working Paper 9730.

Hepburn, C., 2007. Carbon Trading: A Review of the Kyoto Mechanisms. Annual Review of Environment and Resources, 32, 375‑93.

India Energy Portal, 2010. Indian energy sector: an overview. http://www.indiaenergyportal.org/overview_detail.php, retrieved in June 2010.

International Energy Agency, 2009. IEA Scoreboard 2009: 35 Key Energy Trends over 35 Years, IEA, OECD, Paris

JI, 2009. Joint Implementation. http://ji.unfccc.int/index.html, retrieved in June 2009.

Justman, M., Teubal, M., 1996. Technological Infrastructure Policy (TIP): creating capabilities and building markets. In Teubal M., Justman M. and Zuscovitch E. (eds) Technological Infrastructure Policy, an international perspective. Kluwer Academic Publishers.

Klepper, G., Peterson, S., 2006. Emissions Trading, CDM, JI, and More – The Climate Strategy of the EU. The Energy Journal 27, 1- 26

KPMG, 2007. India Energy Outlook. http://www.kpmg.co.il/Events/india/conference/thought%20leadership/IndiaEnergy_07.pdf, retrieved in June 2010.

Kuchler, M., 2010. Unravelling the argument for bioenergy production in developing countries: A world-economy perspective. Ecological Economics, 69, 1336–1343

Lemos, W., 2007. The Brazilian Ethanol Model. ICIS, available at http://www.icis.com/Articles/2007/02/12/4500680/the-brazilian-ethanol-model.html, last access February 2010.

Lewis, J.I., Wiser, R.H., 2007. Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. Energy Policy, 35, 1844–1857.

Nelson, R. R., Peterhansl, A., Sampat, B., 2004. Why and how innovations get adopted: a tale of four models. Industrial and Corporate Change 13, 679-699.

O'Conner, D., 1996. Grow now/clean later, or the pursuit of sustainable development?. OECD working paper no.111 OCDE/GD (96)51, Paris.

Popp, D., 2008. International Technology Transfer for Climate Policy. Policy Brief, No. 39, Center for Policy Research, Syracuse University

REN21, 2007. Renewables global status report. Renewable Energy Policy Network for the 21st Century. Last retrieved May 2010. http://www.ren21.net/globalstatusreport/g2007.asp

REN21, 2009. Renewables global status report. Renewable Energy Policy Network for the 21st Century. Last retrieved May 2010. http://www.ren21.net/globalstatusreport/g2009.asp

Rogers, E. M., 1995. Diffusion of innovations, New York: Free Press.

Schroeder, M., 2009. Varieties of Carbon Governance: Utilizing the Clean Development Mechanism for Chinese Priorities. The Journal of Environment & Development, 18, 371-394

Schneider, M., Schmidt, T.S., Hoffmann, V.H., 2010. Performance of renewable energy technologies under the CDM. Climate Policy, 10, 17–37

Sharp, M., 1998. Competitiveness and cohesion—are the two compatible?. Research Policy, 27, 569-588

Teubal, M., Andersen, E., 2000. Enterprise restructuring and embeddedness: a policy and systems perspective. Industrial and Corporate Change, 9, 87-111.

UNFCCC, 2009. United Nations Framework Convention on Climate Change http://unfccc.int/2860.php/, last retrieved in June 2009.

UNFCCC, 2010. The Mechanisms under the Kyoto Protocol: Emissions Trading, the Clean Development Mechanism and Joint Implementation http://unfccc.int/kyoto_protocol/mechanisms/items/1673.php , last retrieved in September 2010.

van der Horst, G. H., Hovorka, A. J., 2009. Fuelwood: The ''other'' renewable energy source for Africa?. Biomass and bioenergy, 33, 1605 – 1616.

Weiss, E., Jacobson, H., 1998. Engaging Countries: Strengthening Compliance with International Environmental Accords, eds. MIT Press, Cambridge, MA

World Bank, 2003. World Development Report 2003 Sustainable Development in a Dynamic Economy, World Bank, Washington DC.

[1] These factors may play different roles depending on the decisions involved; the adoption of new technologies may involve decisions by individuals or by consensus among the members in a system, or may depend on an 'authority' decision (Rogers, 1995). Energy producing technologies may involve a mix of all three decision-making situations, depending on the type of technology (e.g. solar panels, hydropower), and the specific legal, institutional and corporate settings of each country (e.g. public or privatized national energy companies).

[2] National policy capabilities may be heavily dependent on national natural endowments and on the level of national commitment to comply with global institutional frameworks and national involvement in international cooperation for technology transfer. Hence, it would be difficult to identify whether national policies are designed and implemented to comply with international frameworks or to promote cleaner energy systems. Also, policy capabilities seem to co-evolve with the national levels of economic and social development, technological capabilities and participation in global markets (Teubal and Andersen, 2000). Therefore we focus on measures of national policy culture and capabilities.

[3] Biomass and biofuels projects often force deforestation to expand arable land areas, and the use polluting agriculture methods to raise crops.

[4] It is not clear whether technology transfer includes both equipment and disembodied knowledge.