SD FOR ASSESSING THE DIFFUSION OF WIND POWER IN LATIN AMERICA: THE COLOMBIAN CASE

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Abstract

Given the importance of renewable energy for mitigating Global Warming, without hampering development, this paper explores the feasibility of wind farms in developing economies. The analysis is based on an SD model of electricity markets that represent the behaviour of the agents involved and their decision to invest according to market and/or regulatory incentives - the likely expansion of wind farms depend on such incentives. This research is carried out in the context of the Colombian electricity market and accordingly we take into account likely synergies that may favour the potential exploitation of wind farms in this country. This paper examines how soft regulation may efficiently promote the penetration of wind farms in Colombia.

Keywords: System Dynamics, simulation, renewable energy, electricity markets.

1. Introduction

The world is going through one of the most intense environmental movements that have taken place in history. Since the early nineties important world level conferences and conventions have taken place to discuss such issues: the United Nations Conference on Climatic change, 1992; the Kyoto Convention, December 1997, that agreed on the "Kyoto Protocol"; and more recently, the Johannesburg Conference (United Nations, 2002). During these events, initiatives have focused largely on promoting the adequate use of resources that may help protecting the environment by aiming to reduce greenhouse effects and, at the same time, seeking to avoid major disturbances in the productive capacities of the different economic activities (Concha, 1999).

In this context, the generation of energy from renewable sources is beginning to gather strength throughout the world, motivating leaders to implement actions that might increase the number of projects according to this line of thinking. Latin American is no stranger to this reality and has already developed many such projects for the production of electricity through renewable sources, with the support of the multilateral agencies. Nevertheless, existing initiatives are largely insufficient and have often been the result of efforts of foreign governments rather than those proposed by the communities.

Problems arise when intending to integrate renewable energy into energy policy in the poorer regions of the world, as this may create barriers to development, unless carefully set. This is why we examine in this paper the role of wind farms, the fastest penetrating generation technology at world-wide level, in the Colombian electricity market and the existing opportunities that may arise to generators.

This paper analyses, based on a simulation model that was developed for the Colombian electricity market, the effect of wind farms in the energy sector. We aim to answer the question of how wind farms may play an important role in the process of spreading *clean* power-generation technologies in South America.

2. Evolution of the Latin-American Electric Sector and Barriers to Renewable Energy

The majority of Latin-American countries have introduced major reforms in their electricity sectors. They moved from centrally planned and state owned monopolies to largely privatised and competitive markets, establishing new regulations and institutional set-ups (Dussan, 1996). In this section we examine the different stages of this process and the secondary role that renewable energy has played in it.

During the seventies and eighties, one of the main concerns of Latin America's governments was the need for expanding the provision of energy with the object of promoting economic and social development. This period was characterized by the execution of major infrastructure projects such as reservoirs, electric plants, transmission lines and projects of rural and urban electrification, mainly financed by public funds and multinational agencies such as the World Bank and the Interamerican Development Bank. In practice, little attention was paid to energy efficiency and the generation from new renewable sources like wind power and PVs (Photo-Voltaics).

Expansion plans mainly considered large scale projects and production was focused on the exploitation of a few resources, particularly water and, in a much lower scale, coal.

During the nineties, a new paradigm of organizing the energy sector in a more efficient way was led by Chile and the United Kingdom and this was seconded by multilateral institutions. This resulted in the privatization of state energy companies and the partial deregulation of energy markets in most Latin-American countries. Renewable energy was not a priority to policy makers; the goal was to design a competitive industry and the liquidation of public assets, aiming to serve the public debt of the countries involved and also seeking to meet social needs, as it was case of the privatization of the Bogota Electricity Company (Ayala y Milan, 2003, Cavaliere et al 2006).

In the two stages of the development of the electric sector, energy policy on renewable energy was largely absent (Coviello, 2003). Without specific public policies, this type of technologies cannot propagate further for one main reason: as no environment costs are internalised, renewable energy are in disadvantage with alternative technologies in a more competitive environment. Even though capacity costs are steadily falling for the majority of renewable technologies, these are still more expensive than the traditional ones. In the case of Colombia, at present there is no competitive RE technology (solar, or wind) as electricity pool-price fluctuates around 35 US$/MWh (CDM-PDD, 2003, on line). A favourable regulatory policy might thus be required to contribute to the propagation of not conventional energy sources.

It is worth noting that renewable energy, such as wind and solar, bears intermittence problems. Besides it exhibits a potentially managerial problem to incumbent generators as it tends to operate at considerable smaller scale than traditional technologies (Verdesio, 2004).

Given these entry barriers, gradual internalisation of environmental impacts might facilitate the transition towards a greater participation of renewable energy in the electricity industry (Gieliky, 2002, online).

3. Renewable Energy in Latin America and its Incentives

Although large scale hydro-electricity is not often viewed as an environmentally friendly because of its great impacts on nature and human beings, this has been for many decades a major energy-renewable source in Latin America.

3.1 Latin America and the Caribbean: Potential of Renewable Energy

The composition of the total energy supply in Latin America and the Caribbean indicates that this is a region with a balanced provision of fossilized and renewable natural resources. One can emphasize that the participation of renewable sources represents more than a quarter (25.7%) of the total energy supply. The contribution of hydroelectricity is nearly 15%; wood 5.8% and sugar cane biomass 4.1%. The remaining renewable energy sources such as other biomass (0.5%) and thermoelectricity (0.7%) are marginal (CEPAL y GTZ, 2004).

This indicates that this region has great potential of renewable sources and that in the medium and long run these sources may supply significant amounts of energy if new technologies get sufficient institutional and regulatory support. To this respect, there has already been little progress aiming to exploiting this potential in some countries of the continent that benefit with some incentives support. But up to date statistics indicate that the major resource used is fuel oil as shown in the Figure 1.

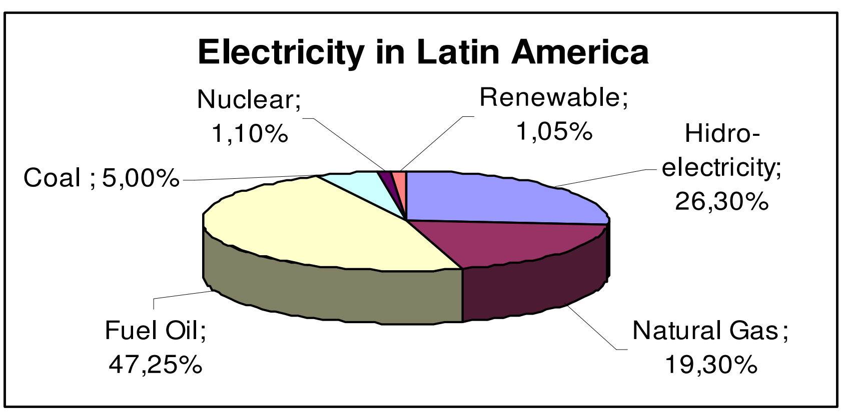

Figure 1. Electricity in Latin America

Source: Statistical Review of World Energy

3.2 Incentives for Renewable Energy in Latin America

Table 1 shows representative cases of the way that renewable energy has been promoted in Latin America. An outstanding fact is that at the present cost of renewable technologies incentives are still limited (Verdesio, 2004).

Table 1. Incentives for Renewable Energy in Latin America

COUNTRY	INCENTIVES
ARGENTINA	• US $ 0.01 per kWh subsidy (15 years at national level) • Tax Exemptions • Benefits for loans • US $ 0.005 – 0.01 subsidies at provincial level • R&D incentives
BRAZIL	• State funds aimed at specific projects
DOMINICAN REPUBLIC	• Tax Exemptions on Equipment imports (15 years) • Tax Exemptions on the generation of renewable energy • Taxes on fossil fuels with the aim of creating a fund to promote alternative energy and programs to reduce 5% of energy consumption
MEXICO	• Discounts of between 50-70% of the transmission and connection costs
COSTA RICA	• Fixed prices for the generation through renewable resources
COLOMBIAN	• Tax exemptions of sales from Alternative Energies (wind and biomass resources) for 15 years. For this exemption it is required to get carbon emissions certificates and to invest fifty percent of the certificates in social infrastructure projects (Law 788 of 2002)

Source: GTZ. 2002

Other countries such as Bolivia, Paraguay and Panama have promoted renewable energy aiming to meet electricity demand in rural isolated zones, where this constitutes an efficient solution (Chermi, 2003, p.7). Nevertheless, these incentives are mainly focused on capital contributions. The current policy of the Interamerican Development Bank and the World Bank, regarding rural energization, favours subsidies on investment (up to 80%) rather than on electricity consumption (Inter American Development Bank, 2005). In addition, most of the policy that has been projected to promote the use of renewable energy in Latin America is supported by international agencies. Particularly, carbon reduction incentives are being introduced in the region, contributing to the generation of electricity through renewable sources.

3.3 Carbon Reduction Markets in Latin America

Renewable energy has emerged in developing countries as an option for the reduction of global Greenhouse effects. That is why funds have been created to finance projects that incorporate the use of renewable energy. Latin America has become the world's main beneficiary of projects associated to CDM (Clean Development Mechanisms)-type instruments. Latin American projects represent 17% of the total funds which have been financed with a variety of world resources (such as the Senter and PCF - Prototype Carbon Fund). The Latin American region is a recipient of 27% of the world credits to CDM projects. Note that with respect to the total amount of funds transacted by banks worldwide (which are still limited), 24% correspond to electricity projects (Ellis and Gagnon-Lebrun, 2004).

Electricity projects are distributed according to technology as shown in Figure 2. It must be emphasized how the majority of them are focused on power generation that use renewable resources. Note that micro-electricity plants take a significant portion.

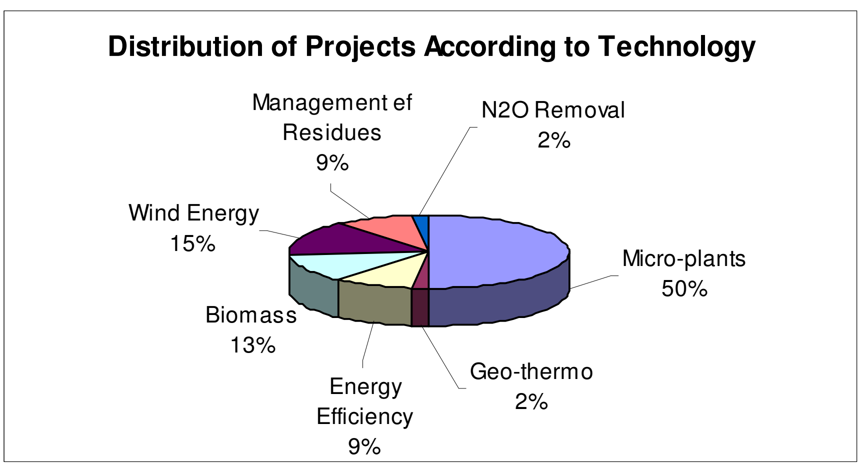

Figure 2. Distribution of Projects by Technology in Latin America and the Caribbean. Source: Coviello. 2003

Among the countries that have presented the largest number of projects are Chile, Colombia, Panama and Costa Rica. This is due to two main reasons: these countries have considerable stocks of renewable resources and have some institutional support to promote CDM.

From world experience, it can be established that there are two approaches to promote renewable energy. The first, through economical incentives within countries and, the second, via multilateral funds aimed to finance CO_2 reduction. Despite that there exist a certain level of incentives in Latin America to increase electricity generation through renewable resources and that the region has been identified as an area of significant economic growth (and therefore significant demand for energy), it has not been determined yet what incentives must be applied systematically in order to attain appropriate levels of technology diffusion for power generation through renewable sources in the region. In the following section we examine, for the Colombian electricity market, the effects that different incentives schemes may have on new power capacity, based on renewable resources.

4. Colombia as a Case to Study the Mechanisms for Promoting Renewable Energy

4.1 The Model

In this paper we seek to assess, using a simulation model, the effect that incentives may have on new renewable capacity in the Colombian electricity market. During the last decade, a great number of policy instruments have been developed and implemented in Europe to support the development of electricity generation projects that use renewable sources. The success of the different policies varies significantly given the great diversity of mechanisms implemented to promote these types of energy. In order to support the selection of instruments, economists have developed a variety of evaluation criteria.

While, during the nineties, the focus was to create markets for renewable energy in Europe and North America, the recently scientific discussion is centred in how to integrate this market segment, artificially created, to deregulated electricity markets (Enzensberger and others, 2002, p. 793). This however has not been the case in Colombia as in this country there is scarce regulation and incentives that promote the use of renewable sources for power generation and therefore complementary markets have not been created for this type of energy. Thus, the challenge is the selection of appropriate policy instrument and the corresponding evaluation tools to assess this possibility.

According to Enzensberger (2002), policy planning in the electricity sector must make use of a techno-economic analysis of the system that considers the corresponding market mechanisms that is in place. That is, one cannot evaluate policies without adequately modelling the way in which electricity markets operate. This problem is associated with technology selection and diffusion. To address this issue, a market model that takes into account technology propagation was developed (see Figure 3). Figure 3 represents the information flows between model components and the main variables involved. Each of the components will be briefly discussed next.

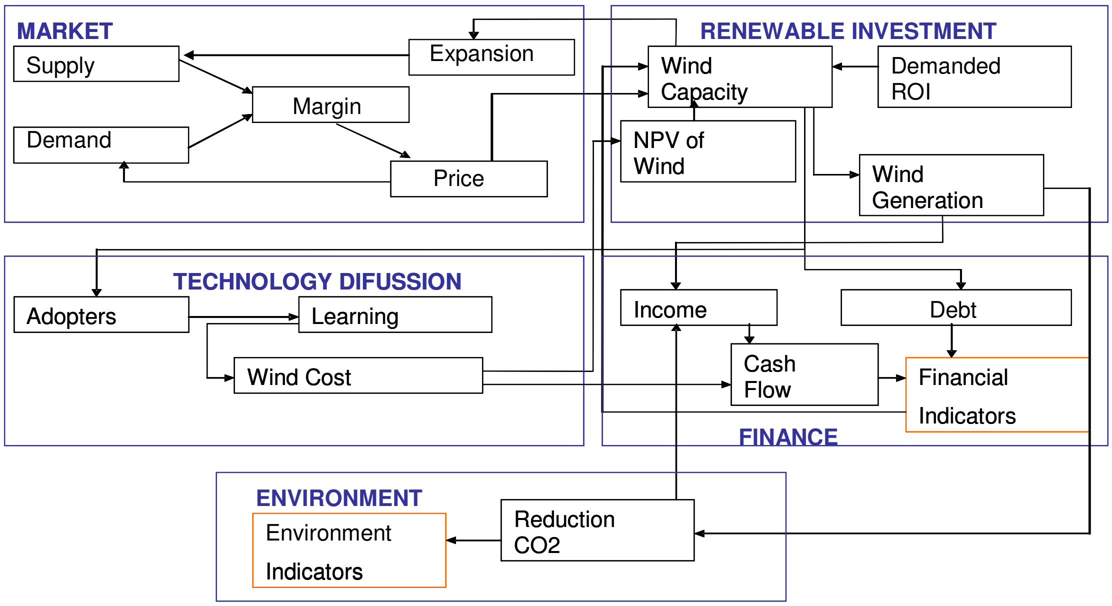

Figure 3. Dynamics of the Insertion of Renewable Technologies in an Electricity Market

4.1.1 Market. This component establishes the price formation of electricity based on historical electricity supply curves and scenarios on demand growth. The variable to be monitored is how the price of electricity evolves in the light of the entrance of new projects and how this price in turn affects the options of carrying out other new projects.

4.1.2 Investment in Renewable Energy. This component represents the main three types of agents that may invest in renewable energy projects. They are basically influenced by: their profitability expectation and the evolution of the projects' NPV (Net present value) in the course of time. In this paper, we assume that there is a learning curve for each technology which is reflected in costs reductions over time (Ibenholt, 2002). Based on this factor, the evolution of the NPV for each MW depends on the installed capacity over time. Other factors that every firm takes into account for investment decisions over time are: the firm debt level and the system margin, which indicates the need for new capacity. Curves represent the capacity to be built according to the NPV obtained from such a project given: the margin of the system (supply of electricity/demand of electricity-1) and the budget restrictions of each firm.

4.1.3 Technology Diffusion. This module establishes the capacity of renewable energy acquired at any given time. It determines the numbers of adopters (agents) that begin to generate through a new technology. Innovation propagates according to a logistic function (Roger, 1995). A gradual growth occurs before the period of experience and then follows a period of rapid growth, finally reaching a plateau. This will induce a costs reduction in generation technologies as shown in Figure 4, making renewable technologies more competitive.

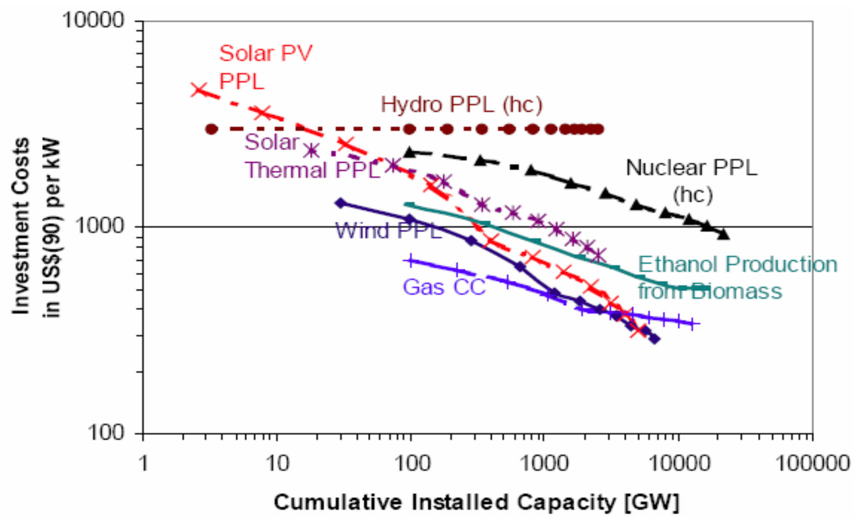

Figura 4: Learning Curve

Source: Barreto and others, 2003

In order to represent technological diffusion in the model, two different alternatives were examined.

Alternative 1 to technology diffusion: It assumes that there exist a potential number of users and that these adopt the new technology in the course of time. Equation 1 governs these processes as follows:

$$y(t) = N[1 - \exp(-t\alpha)] \qquad (1)$$

Where N is the maximum number of potential users and α is the percentage of transmission of new technology, small α means that there is a small diffusion, and $y(t)$ represents the new adopters in the course of time (Geroski, 2000).

Alternative 2 to technology diffusion: Equation 2 indicates the number of adopters in the course of time.

$$y(t) = N[1+\phi\exp(-tk)]\text{^}{-1} \quad (2)$$

Where $k = \beta N$, and $\phi \equiv (N - y(0))/y(0)$ and β is the probability of contact. Small values of β indicate small diffusion (Geroski, 2000).

4.1.4. Environment and Financial modules: These modules seek mainly to obtain variables such as debt level, level of CO_2 reduction, among others, which influences the evaluation of installed capacity under different perspectives. In this model, these modules have little effect on decision and their main purpose is to establish a report on the system evolution.

The model incorporate incentive functions to establish how the system evolves when policies are in place. For this purpose a number of incentive alternatives have been considered as can be observed in Table 2. These incentives have been used extensively in other countries (Gielecki, 2002) and we now analyzed them the context of the Colombian electricity market. The incentives have been categorized according to whether these are financed directly by the taxpayer or these are cross subsidies within the electricity sector itself.

Table 2. Incentives to be evaluated in the Colombian Case

GOVERNMENT
Reduction in income tax
Spending in education and research
Soft loans
SECTOR
Direct subsidies

Incentives in Colombia are all indirect. This means that cash payments are not involved and that only some tax exemptions are applicable. However, further subsidies appeared to be required and this should be efficiently set by Government.

In section 4.3 we will evaluate each of the incentives presented in Table 2 with the purpose of determining the effect of incentives on capacity expansion. Analyzing the effects of incentives on the system it will be possible to determine what policy may efficiently accelerate the process of technology diffusion in Colombia. As has been pointed out by Jaffe *et. al.* (2004), both the theoretical and empirical evidence suggest that the rate of technological progress is influenced by the market and regulatory incentives. In this section we examine the influence of the latter.

4.2 Validation

Systems Dynamics (SD) models intend to produce neither precise results nor exact projections. They represent behaviours and tendencies which may support devising strategies (Dyner, 1993).

SD models should though be validated. In this case validation is undertaken with respect to the electricity spot price. Figure 5 shows how closely the model reproduces historical values observed in the Colombian pool – one of the most important variables of the electricity market.

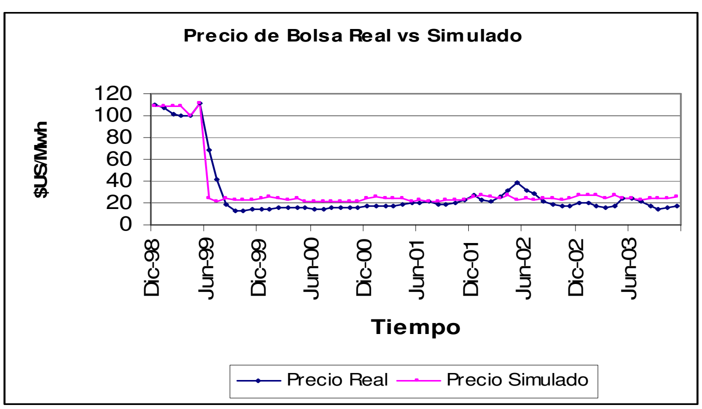

Figura 5. Real spot price vs. Simulate spot price

Further validation tests have been undertaken. These however are not reported in this paper due to space constrains and focus.

4.3 Evaluation of alternative incentive schemes

In this section we evaluate each of the incentives proposed in the previous section but we will first present the base case, that is, the one where no incentives are in place. We seek to conclude how the system may be affected when each of these incentives schemes are applied.

4.3.1 Base Case Scenario

Even though there are modest incentives in Colombia for not conventional energies, the base case scenario considers no incentives – the worst case scenario. In the base case we evaluate the evolution of installed capacity of renewable energy without any kind of incentives, that is, the present income tax of 35%, interest rate of 8% per year and neither subsidies nor promotion of R&D. As can be observed (Figure 6), renewable energy would reach approximately 700 MW of installed capacity; that is, a significant increase over of the present installed capacity.

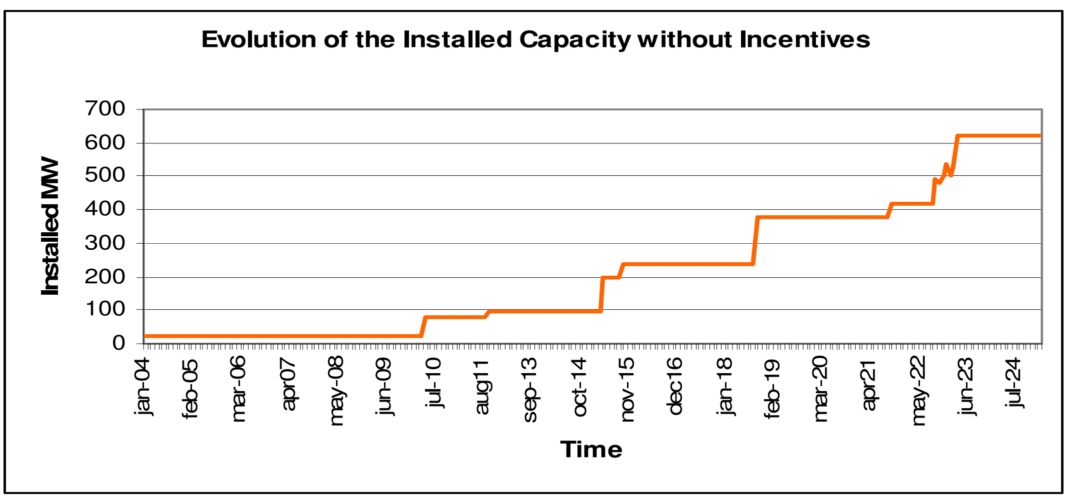

Figure 6. Evolution of the Installed Capacity without Incentives

4.3.2 Spending in Education and Research

Most recent investigations have found that the speed of diffusion of a certain technology is directly related to its profitability and inversely related to the size of investments required and the complexity of the technology (Blackman, Online, 1999). In addition, Audretsch et al (2001) established that there is a linear relation with negative slope between the investment costs in new technology and investment in R&D. That is, the more resources devoted to R&D, the more impact on investments levels, and these in turn will reduce resistance for technology adoption.

We therefore seek to apply the previous concepts in order to determine the effect of spending on R&D on technology diffusion. As we do not know the slope of the line (Figure 7) for the Colombian case, we will need to conduct sensitivity analysis.

Assuming variations in R&D and education spending and that the relation between spending in R&D and the investment costs is given by a slope of -0.1, installed capacity evolves as shown in Figure 12. Simulation shows that investment in R&D does not accelerate the diffusion of the technology during the first few years. The difference is observed when installed levels of 700 MW (Base Case Scenario) are reached, that is, it is when the technology has achieved a certain degree of penetration in the medium term (i.e. when the effects of the spending in investigation become evident). Spending in R&D operates as an accumulator and therefore it is a long-term policy that does not offer visible results in the short term. The parameter in Figure 7 represents investment in R&D in MW per year.

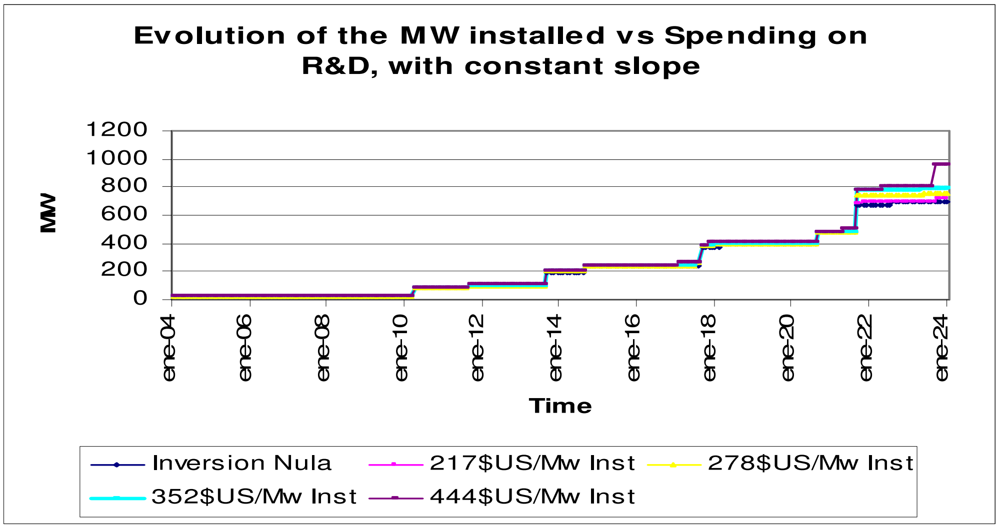

Figure 7. Evolution of Renewable MW (wind) installed vs. levels of spending in research

In addition, it can be observed in Figure 8 that, as more resources are applied to R&D, more capacity becomes available. This indicates that at certain levels of spending in R&D new renewable capacity is installed. That is, only in so far as there is sustained spending in R&D in the course of time there might be further increments in generation capacity. In the Colombian case, the efforts have been reduced and limited to selected education programs and to a small number of R&D projects which should have insignificant effect on technology diffusion.

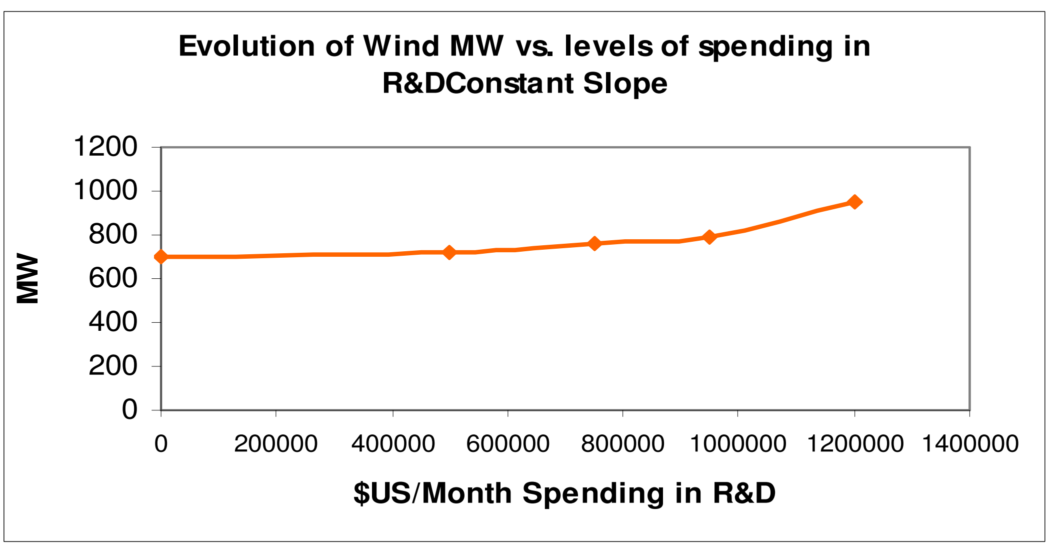

Figure 8. Evolution of Renewable MW vs. Level of spending in investment

Source: Own construction

4.3.3. Reduction of income tax scenario

There is no agreement regarding the effect that tax exemption policies may have over investment decisions or productivity (Walz, 1999). While authors like Ayres (2003) have established that no link whatever exists, others, such as Bemanke, Gerther and Gilchrist (1996), argue that in particular the amount of funds available for investment is supported by tax exemptions. That is, both the average as well as the marginal rate of taxes has an effect on investment decisions (Hasset and Hubbard, 1996). It is not the aim of this paper to present the pros and cons of each of these proposals; in the model we hold a weak causality relation with respect to this issue as we do not assume a direct relationship between the reduction of income tax and the decision to invest by agents, but a relation through gross profits as shown in Figure 9.

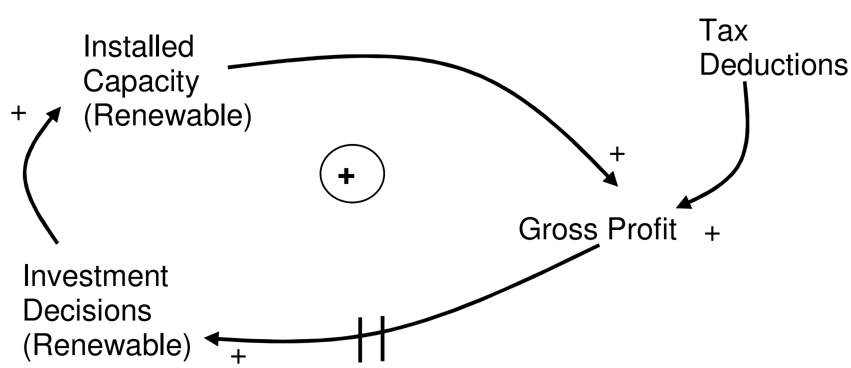

Figure 9. Influence of income tax on the expansion of wind energy capacity

Figure 10 shows how renewable capacity evolves, as there are modifications in income tax. Two cases were considered: a) when taxes amount to 35% of total income and b) when taxes are eliminated. One must note to respect to this point that, as was observed earlier, firms only begin to obtain profits during the last five years of the simulation and therefore the effect is only visible starting from year fifteenth. This means that, although weak, there is a direct relation between taxes and investment. Investment in renewable energy only increases by 100 MW (14% increase in 20 years over the base line) when taxes are eliminated.

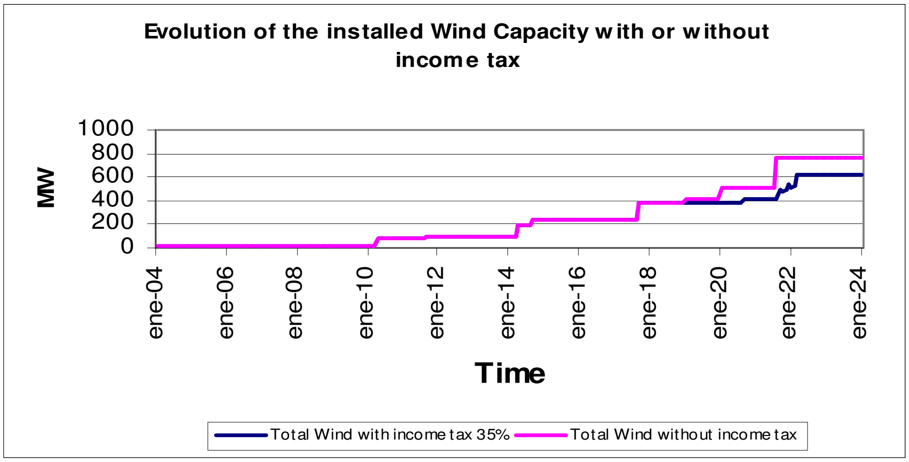

Figure 10. Evolution of the Installed Wind Capacity with or without income Tax

4.3.4. Soft loans scenario

Soft loans are those that have low interest rates and long repayment periods. According to Gotten (2001), investment in technology is influenced by interest rates, taxes and market activity, interest rates being the most important variable. Figure 11 shows how competitiveness is achieved either through costs or through technology and the types of incentives required for the latter to occur. In this case, we conduct sensitivity analysis on interest rate to determine the effect on technology diffusion. The interest rate plays a pivotal role in determining the Net Present Value for renewable energy. In what follows it can be observed how agents respond to variations in interest rates.

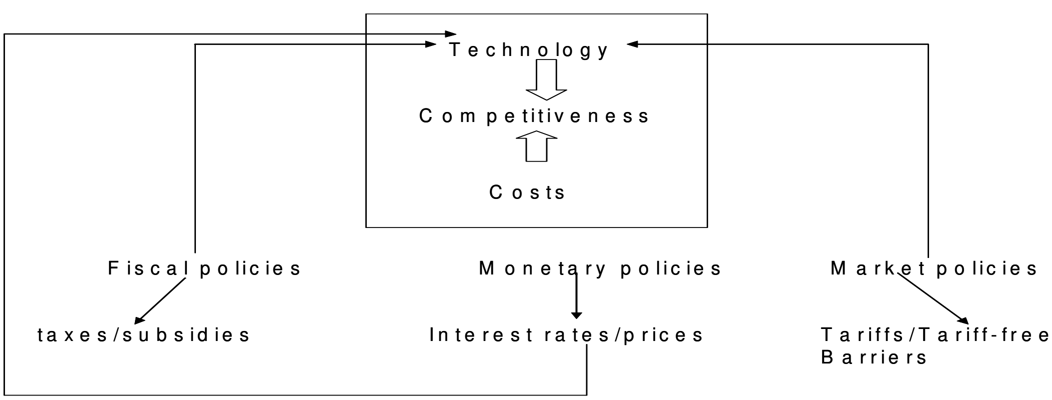

Figure 11. Aspects that have an influence on the competitiveness of a technology
Source: Gotten, 2001

In order to determine the influence that interest rate for loans has over the diffusion of a technology, an exercise is carried out for one agent. That is, we answer the following question: How does interest rate affect the decision to invest in new technology? As an answer to this question, the simulation exercise yields the results shown in Figure 12. It is observed how interest rates over 10% net per year will produce a postponement of up to 5 years in the process of technology expansion, during the period between 2009 and 2014. One must emphasize that as long as the interest rate increases, the agent's total installed capacity of the renewable source is reduced (see Table 3).

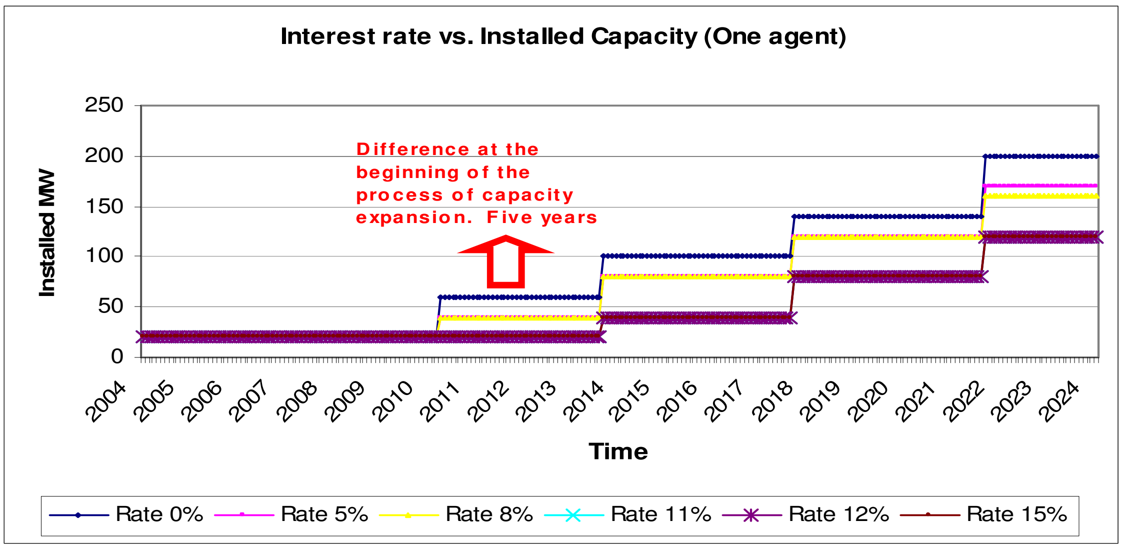

Figure 12. Interest rate vs. Installed Capacity (One agent)

It can also be observed in Table 3 that as the interest rate increases, investment in new capacity diminishes. For every percentage point, the reduction oscillates between 30 and 50 MW. However, with rates above 10% p.a. this effect is neutral and no changes occur for every additional point in interest rates. That is, interest rates over 10% are not sufficiently attractive for the investor to expand his generation plans through renewable resources. Therefore it is necessary that the government facilitate the access to cheap loans because in Colombia the rate for ordinary loans was 17.38% gross p.a. in 2004, although this have come down to less than 10% gross p.a. in 2005 (Banco de la República, Online, 2005).

Table 3. Installed Capacity (Mw) vs. Interest Rates for loans

Interests rates (Effective Annual	Installed Capacity (One agent) MW	Difference
0%	200	
5%	169.4935922	30.5064078
10%	120	49.4935922
11%	120	0
12%	120	0
15%	120	0

4.3.5. Direct subsidies scenario

Direct subsidies are production incentives for which government establish payments for the production of renewable energy (Gielecki, 2002). In the United States these incentives may reach 1 cent per kWh (Rader, 1999). With this reference, we conducted simulations with incentives to producers running from US $2 per MWh to US $15 per MWh, obtaining the results shown in Figure 13. Simulation results show that expansion based on the renewable resource is considerably sensitive to this subsidied. A US $15 per MWh subsidy produces at the end of the period an expansion of the installed capacity of 1500 MW which, with respect to the base case scenario, means doubling the generation capacity. Since at the present time electricity in Colombia is about 35 US$/MWh, a US $ 15 per MWh subsidy represents 42.9% of this price - quite a significant incentive for a small fraction of the total capacity.

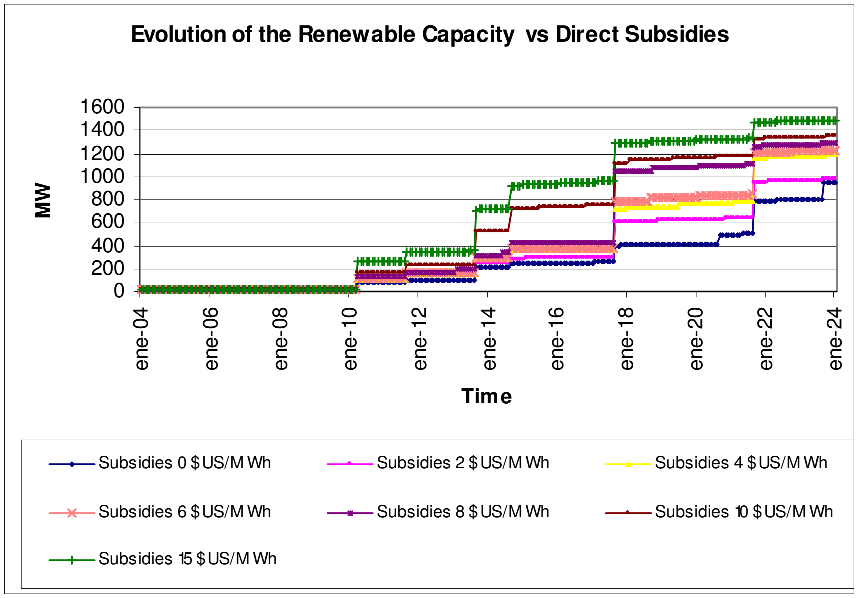

Figure 13. Effect of direct subsidies on installed capacity of a renewable (wind).

From simulations in sections 5.2.1 through 5.2.5, it follows that the most efficient incentive scheme in terms of technological diffusion is direct production subsidies. In addition, it follows that monetary policies such as those based on interest rates play an important role in determining the periods where the process of insertion of the new technology begins. Markets seem to require further incentives to explore and exploit energy potential of renewable given the present cost of *clean technology*.

From an institutional perspective, it means supporting the expansion of renewable sources. As previously shown, the carbon market seems a good prospect for this type of projects and is one of the alternatives for consolidating the market of renewable energy in Latin America; Jepirachi in Colombian (a wind power farm) is a noteworthy case that should be considered - at price levels of 4 to 6 US$/ton CO2 (CDM-PDD, on line, 2003). The State is thus called upon to support the private sector, implementing incentives such as the Clean Development Mechanisms and possibly direct subsidies for the consolidation of this new sector in Latin America.

For some agents, wind farms may offer opportunities as they can make use of the complementarities that exists between hydroelectricity and wind power (Dyner and Zuluaga, 2006). Particularly it has been found that dry and windy conditions are negative correlated in some neighboring regions of Colombia. This might be exploited by some generators as water might be store in reservoirs, and latter sold at higher prices in the form of hydroelectricity. When examining this possibility, we found out under not very favorable conditions that water savings may amount to a fourth of the of reservoir capacity during some dry periods during the year as can be observed in Figure 14. Furthermore, these dry periods coincide with times when electricity is most expensive, making wind power an interesting business.

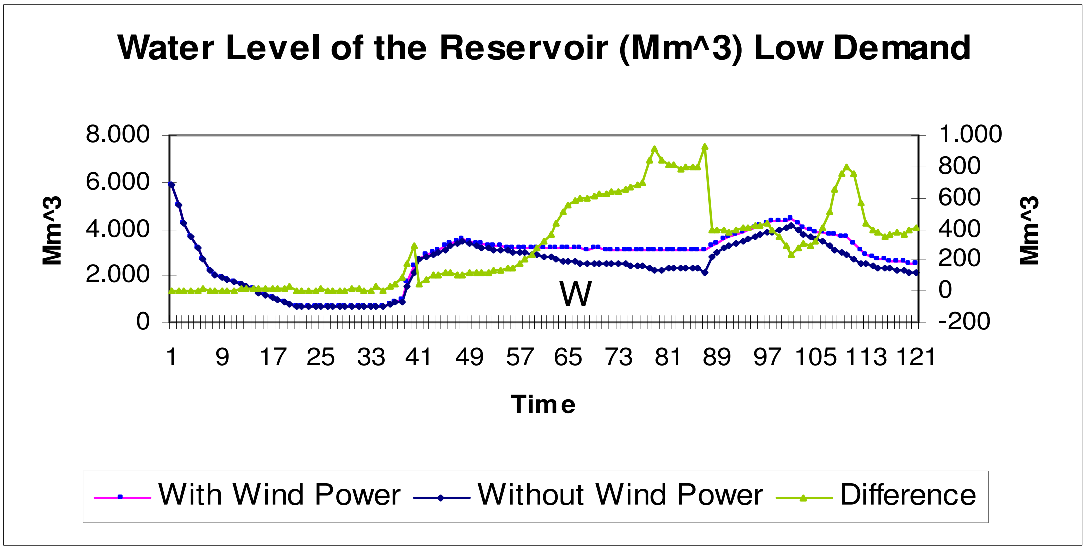

Figure 14. Water level of reservoir under an average hydrology scenario. Time step is giving in months

For an individual generator that does not consider the likely combine profits that arises from sales of hydroelectricity more expensively, the NPV of wind farms is calculated as shown in Figure 15, which proofs profitable, under average conditions.

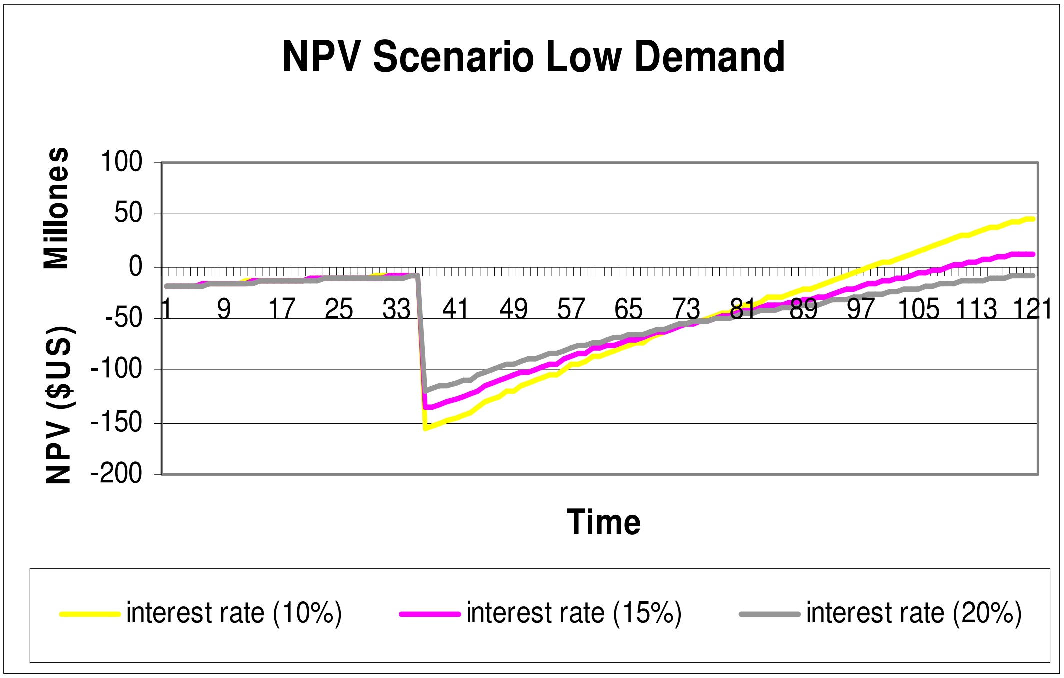

Figure 15. Return on investment for a wind farm operating under an average hydrological scenario.

5. Conclusions

Although poverty is one of the most important concerns in the developing world, there is significant environmental interest associated with the use of new energy sources which can reduce the environmental impacts that have been caused by traditional forms of energy, based on fossil fuels. This is justified also by the existence of funds aimed exclusively to finance projects aiming to reduce carbon emissions in developing countries. These funds constitute a direct way of stimulating new generation capacity through renewable sources.

SD proves to be an appropriate framework to address policy-based issues regarding renewable sources. The SD model that was developed supports the analysis of alternative policy that may speed the penetration of wind power in Colombia.

From simulations carried out for the Colombia market we have concluded that there is low efficiency in the promotion of renewable energies through fiscal policies such as income tax exemption, while other policies such as direct subsidies have a major effect as far as accelerating the process of technology diffusion. Therefore, government has to set the appropriate incentives for the exploitation of renewable energy resources.

Even though renewable energy did not occupy a prominent place when the liberalization processes of electricity markets started to take place in Latin American, it seems that the international tendencies impose new course of actions where this type of energy will begin to play a more central role, especially in meeting the increasing demand of energy as it is now imposed by the processes of industrialization and development.

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