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1. Introduction

Human intervention in the carbon cycle has become a relevant concern in recent times. Global warming is a phenomenon due to the atmospheric concentration of greenhouse gases (GHGs): carbon dioxide, methane, nitrous oxide and chlorofluorcarbons, believed to be irreversible. CO_2 is the most important GHG, its contribution to the radiative forcing of climate is estimated in about 70%.

Changes in the global concentration of these gases depend on: the level of emissions as a by product of economic activities, the natural assimilative capacity of the global ecosystem, and the abatement activities. Notwithstanding the existing uncertainties about the evolution of global warming and its real consequences for human societies and the integrity of ecosystems, the identification of policies and measures to control adverse effects of climate change represents an important issue in national and international agendas.

The global nature of this phenomenon points also to the need for an internationally co-ordinated effort to prevent and control the concentration of anthropogenic GHG in the atmosphere. Recently, on the basis of imperfect information but discernible evidence of human influence on climate change, a 'precautionary approach' has been adopted by the United Nations Framework Convention on Climate Change (UN FCCC), since the Rio Earth Summit in June 1992. The Kyoto Protocol to the UN FCCC agreed after a series of preparatory meetings, on December 1997, strengthened the Rio commitments by defining legally binding emission targets for industrialised countries and creating mechanisms to enrol developing countries in the GHG reduction effort.

The Kyoto Protocol [14] , established targets and timetables for curbing emissions of GHG in industrialised countries and countries in transition towards market economies (Annex I countries). The Protocol sets out targets for curbing emissions of a 'basket' of six GHG in these countries. Total emissions reduction shall reach 5.2% below 1990 levels by 2012. Targets are differentiated by country according to their national socio-economic situation and prospects. Developing countries (non-Annex I countries) are not compelled to cut their emissions but to "enable economic development to proceed in a sustainable manner".

To accomplish this goal, the Protocol proposes different ways to reduce emissions ---individual actions, collective targets or bubbles--- and different mechanism ---Joint Implementation (JI) projects and International Emissions Trading (IET) between Annex I countries and a Clean Development Mechanism (CDM) between Annex I and non-Annex I countries to facilitate the achievement of the reduction targets in a flexible way. Identification of international co-operative projects and evaluation of their benefits drive us to linking different national models under compatible platforms.

In this paper we centre the discussion on the implications of the different agreements and commitments of the Kyoto Protocol on the energy system and economy of Colombia. To do that, we shall make use of different methodologies and tools, to obtain among others the marginal cost of a reduced tonne of carbon coming from abatement measures in the energy sector. One of the tools, we can specially mention is the MARKAL-family of models (MARKAL, MARKAL-MACRO and MARKAL-MICRO). MARKAL [7]---MARKet ALlocation---, is a dynamic process model designed to analyse energy issues within the Energy Technology System Analysis Program (ETSAP) - Annex IV, a cooperative project of national experts under the aegis of the International Energy Agency (IEA). It has has been permanently upgrading to allow for the evaluation of national and multinational GHG

emissions control strategies. This model is being used in more than twenty developed countries since more than two decades and in a few developing countries like India, Colombia, Turkey and Mexico recently.

By linking standardised national or regional MARKAL models, we can evaluate the international co-operation strategies considered in the Kyoto Protocol. On one hand, it is possible to identify cost-efficient ways to curb CO_2 emissions, based on lower marginal reduction costs. On the other hand, we can evaluate the possibilities of the IET between two or several countries, by calculating the pattern of trade.

It is important to note that we did not undertake the evaluation of the potential adverse impacts of the higher global temperatures and see level for the country, except by including uncertainty in water availability when identifying CO_2 emission reduction paths.

2. Colombian Situation

Colombia is one of the developing countries that may be greatly influenced by global GHG emission reduction measures. In the first place, its exports still depend primarily on raw materials. Exports of oil and coal play an important role in the country's balance of payments. Oil is the first export product whilst coal is the third one. In 1995, the contribution of the mining sector to this balance was about 40%.

Next, the country is endowed with a diversity of natural---energy and forestry---resources. It has relatively large oil and natural gas reserves. Excellent quality coal is an abundant resource. The country's hydropower potential was estimated to 93 GW, of which only 10% has been tapped. However, recent environmental regulations may reduce this potential by one third. The electricity is basically produced by hydroelectric plants. Historically, thermal installed capacity and generation have not been more than 30\% of the national installed capacity and annual electricity production. This yields a vulnerable system. During 1992, the country underwent a prolonged period of electric power rationing caused largely by the El Niño phenomenon. Therefore, an increase in the system's firm energy capacity by means of thermal generation is expected.

Final energy demand was growing at a 4% annual average rate while Gross Domestic Product (GDP) was growing at 3.7% annual average rate in the period 1980-1995. Both trajectories have changed since 1995; however if the adjustment program and the peace negotiations are successful, we may expect the previous economic growth path to recover in two or three years. Even if a reduction in the energy intensity is foreseen, the economic development goals will need increasing energy to be accomplished.

Finally, Colombia has a huge cultural and biological diversity which is not extensively known. Concerns about biodiversity could from one side affect energy expansion decisions. New oil reserves, as well as some of the prospective hydrological resources, are located in the zones of high biodiversity. But from the other side, afforestation, reforestation and conservation of natural parks, forestry and land management are attractive options to capture carbon emissions and to produce emissions credits if sink projects are included in the CDM.

Up to now, Colombia's economy activity has not been resulting in a significant contribution to the global warming problem. According to the latest estimations [2], CO_2 emitted in Colombia is about 5.3 tonnes per capita. Land-use changes and deforestation were responsible for about 70% of the CO2 emitted, and the energy activities are responsible for the rest. This figure might have temporarily changed as a result of the recent economic recession and the sharpening of social conflicts. Obviously, the country's developing condition could result in a greater participation in the global emissions if environmental controls are not assumed.

3. Implications of the Kyoto Protocol for Colombia

Table No. 1 shows the emission baselines for Annex I and non-Annex I countries as well as the reduction targets in 2010, as calculated by the MIT Group using the EPPA model[1].

[1] *12 regions are defined in the model: the United States of America (USA), Japan (JPN), the European Union (EEC), other OECD countries (OOE), Eastern Europe (EET), the Former Soviet Union (FSU), Energy Exporting Countries (EEX), China (CHN), India (IND), Dynamic Asian Economies (DAE), Brazil (BRA) and the Rest of the World (ROW). In this table non-Annex I countries are grouped.*

	USA	JPN	EEC	OOE	EET	FSU	Non-Annex I
Baseline 1990	4994	1093	3014	1166	975	3267	7414
Baseline 2010	6730	1555	3901	1731	1448	2798	15187
Kyoto target 2010	4646	1027	2772	1104	1001	3201	15187

Fuente: Ellerman et al. [6], pp. 2-3.

Only five regions of the six Annex I EPPA regions will actually need to take actions to reduce emissions. The reduction effort corresponds to about one third of the expected baseline levels in 2010. The FSU region will fall far below its Kyoto target, originating what is called 'hot air'. According to these previsions, this legal right to emit and thus to sell permits amounts to 8.46% of the whole reduction market. Hot air would undermine the emission trade regime, or as others say, even the whole Protocol regime [8], and it is not fair to non-Annex I countries.

Which portion of this market (4400--4800 Mtonnes of CO2, depending on the decisions about the hot air issue) may be captured by Colombia ? It is difficult to give a precise answer at this very moment. It would depend on the final terms and conditions of the Kyoto Protocol: stronger targets for Russia and Ukraine, ceilings on the use of the flexibility mechanisms, inclusion of sinks in CDM, crediting of permits, compensation measures for energy exporting countries, new and additional financial resources, and organisational framework.

By using MARKAL, we calculate the marginal reduction cost for Colombia reported on Table No. 2[2]. This information allow us to preliminary figure out the technically feasible supply to the Certified Emission Reduction Units' (CERUs') market coming from the energy system. Discount rate is 7% during the 2000--2020 period.

Scenario	Total CERUs (Mtonnes of CO2)	Total Value (MUS$)
- 10 %	138	509
- 20 %	334	2333
- 30 %	535	5814
- 40 %	735	10697
- 50 %	929	17063
- 60 %	1126	24907
Stabilisation	1270	32202

Fuente: A. Cadena [5], pp. 159

[2] *See A. Cadena [5]*

If sinks were included in the CDM, the Colombian supply will move up. Despite this, it may not straightforwardly be sustained that Colombia will become an important producer in the CERUs market and that the income of this activity will be an important item of the balance of payments. Nevertheless, they could have important positive impacts for development as we discuss below.

Based on the MARKAL models, we develop two studies to identify cost-efficient ways to curb CO_2 emissions in the energy sector between Switzerland and Colombia. The work was done in collaboration with a team of Paul Scherrer Institute. In the first study [3], we use the methodology for identifying potential CDM (or JI) projects based on lower marginal costs to curb CO_2 emissions in a host country, in this case Colombia, that an investor country, in this case Switzerland, could finance to comply with its emission reduction commitments. In the second case [12] we evaluate the possibilities of the IET between the two countries by calculating the pattern of trade and the market and the social prices of the CO_2 emission permits.

By using the MARKAL models, a baseline CO_2 emission path in Colombia was first determined [4, 5]. Using a Swiss-Colombian multinational MARKAL and MARKAL-MICRO models, we consider then the two mentioned co-operation strategies between Switzerland and Colombia to curb jointly CO_2 emissions. The multinational models minimise the total energy and emission control cost of the two countries to reach global CO_2 emission reduction targets. They enable a preliminary identification of projects in the Colombian energy system and illustrate the benefits to be gained through international co-operation to reduce CO_2 emissions. Any of MARKAL, MARKAL-MICRO or MARKAL-MACRO can be used as a standard tool to perform a first good evaluation of the alternatives considered in the Kyoto Protocol to jointly curb GHG emissions.

The numerical applications clearly indicate the attractiveness of the Kyoto flexibility mechanisms for

developed countries, which can expect substantial savings for complying with the commitment to reduce CO_2 emissions. Developing countries may benefit from an improved energy system and/or environment. To perform the final selection of the strategy to be followed and projects to be implemented, cost-benefit analyses should be used to take into account all direct and indirect costs and benefits associated with the actions finally selected (e.g., monitoring and verification costs, indirect environmental benefits and costs, leakage effects). The risk sensitivity of these mechanisms should be analysed by using more suitable tools like real options or contingent-claims analysis approaches. Prices and paths for emissions trading should also been identified. Developing countries should aim at designing an optimal path to sell its emission reduction units, which can be viewed as a natural (environmental) resource. Developed and developing countries should ensure that the economic advantages of the flexibility mechanisms would not be offset by the reduction of its innovation capacity and technological learning processes.

For Colombia, the critical point of the Kyoto Protocol, at least in the short and medium term is the potential reduction in the world prices for fossil fuels, mainly for coal. A decrease by one dollar per metric tonne traded in the international coal market will entail a reduction in income from 30 to 60 millions dollars. Thus, the decrease by 5 dollars per metric tonne foreseen by ABARE [1] will result in an income reduction from 150 to 3000 millions dollars per annum, that is between 2.5% and 5% of the corresponding steady state mining exports in 2010.

4. Concluding Remarks

The 'dark' panorama for the coal industry, shows us that the major efforts of the energy exporting negotiators, including Colombia, must be focused on getting the acceptation of removal by sinks in the CDM or the widening in the IET market as a compensation measure. GHG emissions produced by the combustion of imported fossil fuel in Annex I countries will be offset in the resource origin. In such a way, fossil fuel coming from developing countries will be economically and environmentally competitive with cleaner fuels. And none additional mechanisms or distorting---exceptional and exempting--- compensations measures should be considered. If energy exporting countries succeed in obtaining this, the implementation of an efficient and effective Green Coal Market (GCM) must be a priority for our country.

Reforestation, afforestation, land-use changes and perhaps conservation projects are appealing options for both Kyoto Parties. On one hand, CERUs prices will most likely go down and so the burden of reaching reduction targets. On the other hand, multi-purpose projects with a wide local participation will exhibit positive direct and indirect benefits allowing depressed areas to find new opportunities and channels to improve their life conditions. The potential negative impacts of cheaper CERUs and emissions permits system like the slowing down of the innovation processes might be overcome with adequate R&D policies world-wide, recognising that the heaviest weight would be supported by industrialised countries in the short and medium run.

Considerations about sinks (forestry and land-use) options make us reflect on the elusive aim of the UN FCCC: 'to enable societies to develop in a sustainable manner'. If no substantial but incremental changes in our conception of 'well being and economic success' [10] would take place, we could anticipate that sustainability would just be a way to emphasise the distributional concerns that the previous development concept has left aside. We would have taken a few steps forwards. However, the intense academic activity that the environmental and globalisation concerns have propitiated lately, makes us expect radical modifications in our conception about a sustainable future and better methodologies and tools for facing rapid and complex system and situations. For the time being, it is important to go on solving our present problems through eclectic approaches that take advantage of all positive aspects of the different disciplines and development models.

In the Colombian case, the social, economic and natural situation is extremely delicate. The country is still very far from the 'freedom, equity and economic progress' reached by advanced nations [11]. Economic programs and instruments should aim at promoting a more efficient, equitable and participative institutional framework without underestimating the 'corporative and clientelist organisation that has prevailed in our country for long time'[3]. International credits and financing should not be the exception. In this context, the forestry projects,

[3] *See S. Kalmanovitz [11], p.*

we have been discussing, should help rural areas to overcome their actual depressed conditions. Energy or environmental objectives must be subordinated to the 'golden' search for complete, robust and sustainable development solution. The criteria proposed by the Colombian team in charge of the sink portfolio, to select and approve removal projects [13] seem to be in this direction.

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