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The economics of climate change in Latin America and the Caribbean: stylized facts

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This article aims to provide an overview of the main regular patterns in the economic impacts of climate change in Latin America and the Caribbean, including the corresponding adaptation and mitigation processes. The key results show that the economic costs of those impacts in Latin America and the Caribbean are significant, heterogeneous, nonlinear and growing over time; and that there are specific thresholds beyond which irreversible losses occur. The available evidence also reveals a positive relation between the trends of per capita emissions, energy consumption per capita and income per capita. Projections are for per capita emissions to continue to grow regionwide, with the levels for individual countries converging in absolute terms; and at the same time emissions will gradually become decoupled from economic activity.

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I
Introduction

Climate change is one of the key challenges of the twenty-first century. The available scientific evidence shows that greenhouse gas emissions —caused essentially by human activities— are generating large-scale climate changes, involving a rise in global temperature, changes in rainfall patterns, shrinking ice caps and retreating glaciers, rising sea levels and increases in the intensity, frequency, or both, of extreme weather events (IPCC, 2007). These climate changes can be expected to have significant repercussions for human activities and the planet's ecosystems. In particular, economic activities will face the simultaneous challenge of adapting to new weather conditions and implementing major mitigation processes to avoid the most extreme climatic scenarios.[1] The scale of the economic costs expected in this century suggests that climate change will be an additional constraint on economic growth for the countries of Latin America and the Caribbean.

The economic analysis of climate change is therefore essential for designing and implementing a consistent adaptation and mitigation strategy, to reduce or avoid the most extreme economic costs arising from this phenomenon and optimize the use of available resources. Nonetheless, this is a complex task in which the long-term costs and benefits of each public-policy alternative need to be weighed, and appropriate risk management implemented in a context of high uncertainty (Pearce and others, 1996; Stern, 2007; Mendelsohn and Neumann, 1999; Tol, 2002). Not surprisingly, this involves an intense ethical and international political debate over the distribution of costs between countries, and between sectors and economic groups, with emphasis on adaptation and vulnerability, or on mitigation and compliance mechanisms and the respective sanctions (see, for example, *Oxford Economic Review of Economic Policy*, 2008).

The key aim of this article is to present a long-range overview of the main regular patterns observed between economic activities and climate change in the region. It thus attempts to contribute to discussions aimed at defining the best adaptation and mitigation alternatives to tackle the problem of climate change from the Latin American and Caribbean standpoint, and to improve understanding of the consequences that the various types of international agreements could have for the region.

The economic analysis of climate change is surrounded by major uncertainty, since it includes a wide variety of factors in which the transmission channels and scale of the effects are not sufficiently understood. It is a very long-term phenomenon with feedback processes, and it includes complex risk-management procedures. Hence, the projections set forth in this article only represent potential scenarios which are highly uncertain and should not be taken as point forecasts.

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[1] Mitigation processes involve reducing greenhouse gases.

II

The evidence for climate change

Atmosphere and climate models, supported by the available evidence, show the presence of globally discernible climate changes that can only be correctly simulated by including factors of natural and anthropogenic forcing (IPCC, 2007), such as:

i) A gradual but continuous rise in global temperature, although with significant differences across the regions of the world. This shows a discernible rise in temperature of 0.7°C between the periods 1850-1899 and 2001-2005. This is also consistent with evidence of a reduction in the number of cold days, an increase in the number of extremely warm days, and a rise in sea temperature.

ii) Significant changes in rainfall patterns, which are intensifying current hydrological cycles; for example, heavier rainfall in very humid areas and less rainfall in dry areas.

iii) Changes in the types, patterns and frequencies of extreme weather events, although doubts remain regarding future changes in the probability distributions of such extreme events (Vincent and others, 2005; Aguilar and others, 2005; Kiktev and others, 2003).

iv) A rise in sea level of 0.17 m in the twentieth century, as a result of the melting of the cryosphere, among other factors.

v) Significant collateral climate effects, such as changes in patterns of evapotranspiration, changes in ocean salinity and also in wind patterns and ocean currents.

Climate projections (IPCC, 2007) for the twenty-first century suggest an increase in temperature of between 1° and 6° C, depending on the emissions scenario considered, a rise in sea level averaging roughly 0.50 m, changes in rainfall patterns, a shrinking of the cryosphere and retreat of glaciers, and changes in the type, intensity and frequency of extreme events.

The evidence available for Latin America and the Caribbean is consistent with global trends, with even more intensive effects in some regions. For example, projections show greater temperature increases in tropical or warm regions, more frequent extreme events in the Caribbean and Central America, changes in climate patterns, such as the El Niño and La Niña phenomena, and changes in rainfall which in the future could vary between increases of 5% and 10%, and decreases of between 20% and 40% (ECLAC, 2009a).

III

The methodology of the economic analysis of climate change

The economic analysis of climate change is a complex subject that calls for a wide variety of techniques and economic methods (Nordhaus and Boyer, 2000; Stern, 2007; Galindo, 2009; ECLAC, 2009a), drawing on various sciences and approaches. There is intensive debate over the importance of the topic, the public policies needed and the best time to implement them. In principle, the economic analysis of climate change starts by identifying and defining a baseline, inertial or habitual path, representing business as usual (BAU). This is used as a benchmark comparator for the economic effects and also for adaptation and mitigation processes (ECLAC, 2009a) (see figure 1).

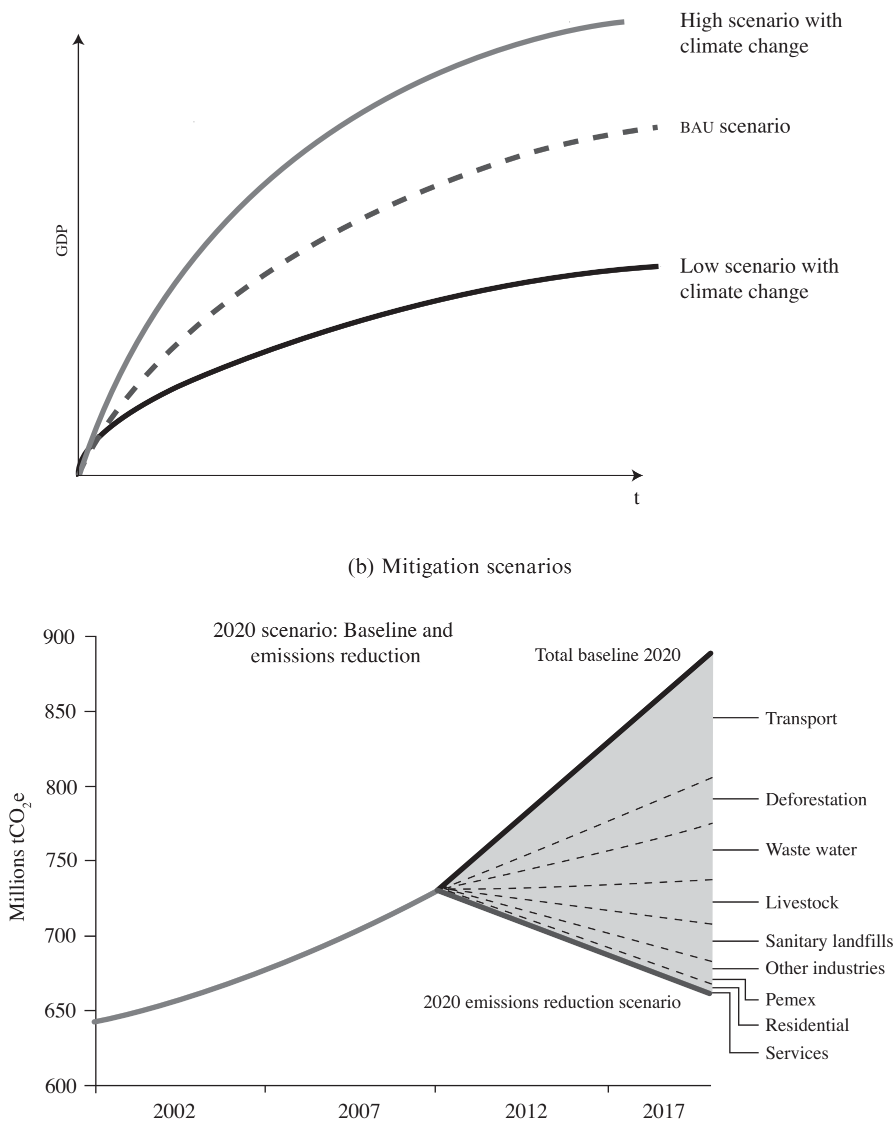
In this context, climate change also has specific characteristics that condition the results of economic analysis, including:

1. Climate change is a phenomenon that unfolds over long periods of time, with high levels of uncertainty. It is therefore necessary to construct very long-term scenarios based on the best information currently available; but these do not represent specific predictions. It also needs to be recognized

FIGURE 1

Emissions scenario and abatement wedges

(a) Impact scenarios



Source: Prepared by the authors on the basis of Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of climate change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009; and Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007. The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, Cambridge University Press, September 2007.

t: Time.
GDP: Gross domestic product.
BAU: Business as usual
Pemex: Petróleos Mexicanos.
tOC:$_2$e: Tons of CO_2 equivalent.

that there is very limited capacity to make relatively precise projections 100 years into the future. In fact, the available econometric theory (Clements and Hendry, 1999) shows that optimum forecasts can only be obtained with a correctly specified model with stationary time series and without structural changes —assumptions that are unlikely to be fulfilled in the economic analysis of climate change.

2. Climate change is a non-linear phenomenon in which there is a considerable component of risk regarding the likely occurrence of extreme weather events. Designing and implementing an adequate strategy against climate change requires, from the economic perspective, implementation of appropriate risk management; in other words, it is necessary to "take out insurance" against the possibility of the most extreme weather events occurring, but which have a low likelihood of occurrence. Nonetheless, risk management by most of the population displays a number of biases that lead to inefficient management. For example, it has frequently been noted that the population incorrectly estimates the likelihood of certain phenomena occurring; that it assigns a different weight to alternatives that depend not only on economic considerations but also on ethical or moral factors; or that economic agents are strategic but shortsighted, since they do not have an infinite horizon and only consider a finite number of interactions (Dixit and Nalebuff, 1993; Levitt and Dubner, 2005; Bernstein, 1998). In this regard, the construction of appropriate risk management should be based on identifying the long-term probabilities of climatic phenomena occurring, and estimating their respective economic costs and benefits.

3. The economic analysis of climate change therefore calls for a weighting of the potential economic costs and benefits of various public policies between different groups of society and between generations, and even between ecosystems. To achieve this, cost-benefit analysis is commonly used as a general framework. This makes it possible to compare aggregate economic costs and benefits at different points in time, normally using the concept of net present value, and applying a chosen discount rate (Nas, 1996; Johansson, 1993; Hanley and Spash, 1995; Layard and Glaister, 1994). Choosing the discount rate is not exclusively a technical problem, but includes important ethical and equity considerations. For example, it reflects an ethical opinion of the importance to be given to future generations and conservation of the current environment for the future. Cost-benefit analysis uses an intergenerational social welfare function, which should be maximized through time (Hanley and Spash, 1995).[2]

This generational welfare function represents a compound index of the set of goods and services available to each generation, which is needed to make comparisons between generations that will obviously consume different baskets of goods and services. It is defined as follows:

$$Wt = F(U_{1t} + U_{2t} + \ldots + U_{nt})\ i = 1,2,\ldots, n \qquad (1)$$

where each U_i represents the social welfare function of each generation in time t. In the conventional theory, welfare is maximized when marginal utilities are equal over time. This requires the utilities of the different generations to be comparable, for which it is essential to apply a pure discount rate (δ), known as the pure time-preference rate, to the respective welfare functions. The intertemporal utility function can then be represented continuously (Hanley and Spash, 1995; Johansson, 1993) as:

$$W = \int_{t=o}^{n} e^{-\partial} U_t(ye_t)dt \qquad (2)$$

where, for simplicity, welfare is made a function of equilibrium income (ye_t) or consumption; and an increase in income is deemed to reduce marginal utility through time.[3] Thus, the net present value of monetary flows at different points in time can be estimated with the following equation:

$$VPN_t = -INV_o + \sum_{n=o}^{n} \frac{VN_t}{(1+r)^n} \qquad (3)$$

where NPV is net present value, INV_0 is the initial investment at time zero, VN_t is the net value at different moments in time, and r is the discount rate. In this context, a high (low) discount rate obviously involves giving less (more) importance to the future. The discount rate can be defined using the well-known Ramsey equation (equation (4) (Ramsey, 1928; Blanchard and Fischer, 1989), which includes:

[2] Discussion on intergenerational welfare functions naturally includes other aspects (see, for example: Johansson (1993); Mishan and Quah (2007); Layard and Glaister (1994).

[3] The existence of a social welfare function has been strongly criticized (Mishan and Quah, 2007).

— The pure time preference rate (δ)
— The elasticity of the marginal utility of income or consumption (α)
— The rate of growth of equilibrium income or consumption (g)

$$r = \delta + \alpha g \qquad (4)$$

where the first two parameters are not observable. Thus, the pure rate of time preference, or temporal discount rate, estimates the importance attached to the welfare of future generations and reflects impatience for income or consumption, such that future income or consumption are valued less than current consumption. The second parameter is the declining rate of marginal utility of income, and represents the value attached to an additional unit of income; for that reason, this rate is multiplied by the growth rate of equilibrium income (ye) to estimate the total impact. Future generations with a higher level of income will thus have a lower marginal utility than one unit of income, for which reason future risk needs to be weighted by income level (Nordhaus, 2008). In that way, this term reflects the generations' inequality aversion. A low level of (α) means that whether the future is richer or poorer is seen as relatively unimportant; in contrast, a high (α) means that whether the future is richer or poorer matters a lot to the present generation. In short, choice of the discount rate is a description of how economic agents currently respond, and how they view the future, together with their value judgments (Hanley and Spash, 1995; Mishan and Quah, 2007; Stiglitz, 1983; Layard and Glaister, 1994). Thus, deciding what discount rate to use is both a technical estimate and an ethical decision. Moreover, when evaluating the conditions of sustainable development, the appropriate discount rate is usually different from the rate that would be used to evaluate a specific project. In any event, the economic analysis of climate change needs to recognize that results are highly sensitive to the interest rate chosen, given the long periods of analyses involved (Campbell and Brown, 2003).

In the economic analysis of climate change, a social preference rate is often applied that is different and usually lower than the market interest rate, for three reasons (Hanley and Spash, 1995; Sen, 1997):
— There is a sense of great responsibility towards future generations, which needs to be reflected in the discount rate used.
— The population has a dual role to the extent that is more concerned for future generations than about its role as consumers.
— The solitary effect, in other words the fact that individuals on their own save less than collectively.

IV
The repercussions of climate change on economic activities in Latin America and the Caribbean

The available evidence shows that climate change will have considerable effects on economic activities this century (Stern, 2007; Nordhaus, 2008; Galindo, 2009; ECLAC, 2009a and 2009b). These economic costs are generally significant, heterogeneous, nonlinear, irreversible and increasing through time; and, in many cases, they display asymmetric behaviour and exert greater effects on the less developed regions, which have less capacity to adapt. The magnitude of these effects means that the expected costs in Latin America and the Caribbean this century will represent a large proportion of current gross domestic product (GDP) and will force changes in the behaviour patterns of economic agents. Moreover, the costs rise as temperature increases and could breach specific thresholds causing faster or irreversible losses. The trend of these costs is also expected to differ widely between regions, so there are geographic areas that obtain temporary economic gains, for example the with a temperature increase below the 2ºC threshold, or through the cultivation of specific products.

On the whole, the available evidence suggests that the most significant economic repercussions are concentrated in the following areas (ECLAC, 2009a):[4]

— Smaller crop yields as a result of rising temperatures and changes in rainfall patterns. There are also temporary gains (usually up to temperature increases of 2ºC) related to the expansion of the agricultural frontier in the more temperate Latin American and Caribbean countries. In contrast, in tropical regions and in Central America, temperature increases will have direct negative effects. In addition, there is evidence (Ecuador) that these climate impacts will be more intensive in the lowest-income sectors whose adaptation capacity is less (see figure 2) (ECLAC, 2009a).
— Intensification of land degradation and desertification processes. Projections up to 2100 suggest that between 22% and 62% of total land area will suffer degradation in countries such as Chile, Ecuador, Paraguay, Peru and the Plurinational State of Bolivia (see figure 2) (ECLAC, 2009a).
— Changes in land use and more frequent forest fires, with a likely intensification current trends (see figure 2).
— Retreat of glaciers, which will affect the availability of water for human consumption, hydroelectric power generation and water supply for economic activities. In addition, changes in rainfall patterns generate changes in the availability and provision of water (ECLAC, 2009).
— Significant biodiversity losses, particularly in a number of forest and tropical regions and in Central America. For example, there is a serious risk of loss of the coral reef in Mexico and Central America, and of a number of endemic species in the region (see figure 2) (ECLAC, 2009a).
— An increase in the frequency of extreme weather events, particularly in Central America and the Caribbean, but also in a number of South American countries, owing to the effects of El Niño and La Niña (ECLAC, 2009a).
— A rise in sea level, which will destroy mangrove swamps in countries such as Brazil, Colombia and Ecuador; flooding in coastal zones such as Río de la Plata; a deterioration of fishing activities and physical infrastructure; an increase in socioeconomic and health problems in certain regions (Magrin and others, 2007; ECLAC, 2009a).
— Propagation of diseases and pests in the region; in particular, an increase in diseases such as dengue fever and malaria and the effects of heat waves.

A sample of the economic costs related to climate change projecting to 2100 is summarized in tables 1 and 2, which reveal significant differences across countries, in this case between Chile and Mexico.[5]

These disparities in economic costs between countries reflect significant differences in terms of climate predictions and conditions, geographic and orographic conditions, productive structures, relative price vectors and institutional and regulatory arrangements (Galindo, 2009; ECLAC, 2009b).

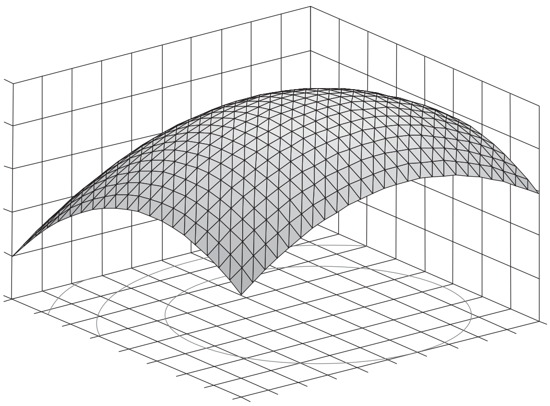
[4] This subsection is based essentially on analyses made in regional studies of the economics of climate change in Latin America and the Caribbean, coordinated by ECLAC and summarized in ECLAC (2009a).

[5] The scenarios used by the Intergovernmental Panel on Climate Change to project CO_2 emissions, consist of six scenarios A1F1, A1T, A1B, A2, B1, B2, which include indicators of the key demographic, economic and technological determinants of greenhouse gas emissions. The A1 family of scenarios is foresees rapid economic growth, a world population that reaches its peak value in mid-century and a rapid introduction of new technologies. This A1 scenarios include A1F1, characterized by intensive use of fossil fuels, A1T which features the use of non-fossil energy sources, and A1B which maintains a balanced use of all types of energy source. The A2 scenario family describes a highly heterogeneous world, in which economic development is basically oriented towards the regions and where economic growth and technological change are slower than in the other scenarios. Scenario B1 envisages a converging world with economic structures changing towards a services and information economy, involving less intensive use of materials and the introduction of clean technologies with successful exploitation of resources. Scenario B2 is oriented towards economic, social and environmental sustainability, with intermediate levels of economic development and slower and more diverse technological changes than in scenarios B1 and A1.

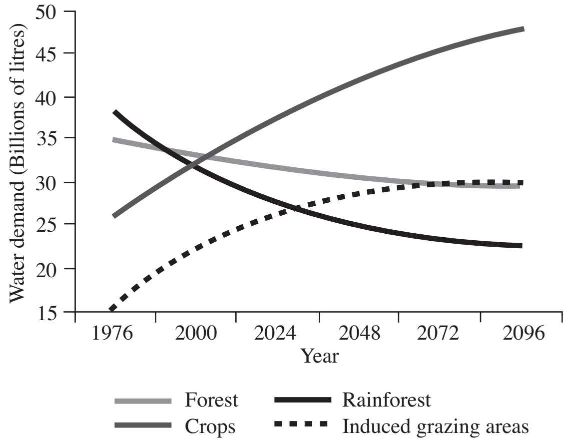
FIGURE 2

Economic trends and repercussions of climate change

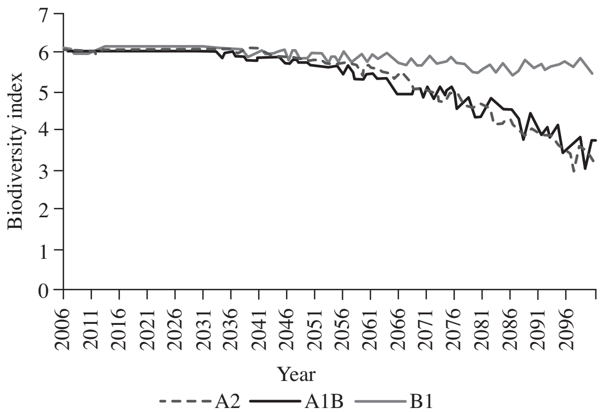
Central America: Crop yields



Mexico: Coverage projections based on the transition observed between 1976 and 2000



Mexico: Biodiversity index under various climate change scenarios



Estimated losses caused by land degradation in certain countries

	Degraded area (Km^2)	Percentage of territory	Degraded area 2100	Percentage of territory 2100
Bolivia (Pl. St. of)	60 339	5.49	243 979.4	22.2
Chile	77 230	10.2	312 277.8	41.2
Ecuador	40 136	14.15	162 289.0	57.2
Paraguay	66 704	16.4	269 716.2	66.3
Peru	197 211	15.34	797 418.4	62.0

Source: Luis Miguel Galindo, *La economía del cambio climático en México: síntesis*, Mexico City, Ministry of Finance and Public Credit/Secretariat of the Environment and Natural Resources, 2009; and Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean: Summary 2009* (LC/G.2425), Santiago, Chile, November.

TABLE 1

Chile: Costs of climate change, 2100

(Percentages of GDP)

	Discount rate 0.5%		Discount rate 2%		Discount rate 4%	
	A2	B2	A2	B2	A2	B2
Total direct impacts	0.78	0.02	0.68	0.09	0.57	0.18
Total indirect impacts	0.31	–0.1	0.28	–0.04	0.25	0.05
Total impacts	*1.09*	*–0.09*	*0.96*	*0.06*	*0.82*	*0.23*

Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean: Summary 2009* (LC/W.288), Santiago, Chile, December 2009.

Note: Scenarios A and B represent socioeconomic scenarios defined by the Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007. The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, Cambridge University Press, September 2007.

TABLE 2

Mexico: Costs of climate change, 2100

(Percentages of GDP)

	Discount rate 0.5%				Discount rate 2%				Discount rate 4%			
Sector	B1	A1B	A2	Average	B1	A1B	A2	Average	B1	A1B	A2	Average
Farming	7.5	11.2	11.1	9.9	3.3	4.8	4.6	4.3	1.4	1.9	1.7	1.7
Water	18.9	18.9	18.9	18.9	9.4	9.4	9.4	9.4	4.5	4.5	4.5	4.5
Land use	–0.4	–0.3	–0.2	–0.3	–0.1	–0.1	0.0	–0.1	0.0	0.0	0.0	0.0
Biodiversity	0.2	0.7	0.7	0.5	0.1	0.2	0.2	0.2	0.0	0.1	0.1	0.0
International tourism	0.1	0.2	0.2	0.2	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Total	*26.2*	*30.6*	*30.6*	*29.2*	*12.7*	*14.5*	*14.3*	*13.8*	*5.9*	*6.5*	*6.3*	*6.2*
Livestock breeding	3.8	5.3	5.2	4.7	1.7	2.3	2.2	2.1	0.7	0.9	0.9	0.8
Biodiversity - indirect	3.6	8.5	7.6	6.6	1.4	3.0	2.6	2.3	0.4	0.8	0.7	0.6
Total ((including livestock and biodiversity- indirect)	*33.6*	*44.4*	*43.4*	*40.5*	*15.8*	*19.8*	*19.1*	*18.2*	*7.0*	*8.2*	*7.9*	*7.7*

Source: Luis Miguel Galindo, *La economía del cambio climático en México: síntesis*, México, D.F., Ministry of Finance and Public Credit/Secretariat of the Environment and Natural Resources, 2009.
Note: Scenarios A and B represent socioeconomic scenarios defined by the Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007. The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, Cambridge University Press, September 2007.

V

Regular emission patterns

The climate simulations undertaken (see table 3) suggest that a concentration level of 450 parts per million (ppm) of CO_2e (CO_2 equivalent)[6] means a 78% probability that temperature will rise by 2ºC with respect to current levels, and an 18% chance that it will rise by up to 3ºC (ECLAC, 2009a). With concentrations of 550 ppm, there is a 99% chance that temperature will rise by 2ºC, a 69% likelihood of its rising by 3ºC, and a 24% probability that it will increase by 4ºC. In this context, a mitigation strategy that seeks to stabilize emissions at current levels already entails significant climate effects, which should be considered inevitable and require an adaptation strategy.[7] Nonetheless, it needs to be recognized that the option of stabilizing at 450 ppm substantially reduces the most severe climate effects that will occur following temperature increases of 2º or 3ºC, and it also reduces the economic costs of mitigation (Stern, 2007). In contrast, a strategy of stabilization at 550 ppm involves significant economic costs, since it allows for the possibility of a significant increase in extreme weather events and feedback climate processes that could cause even higher temperature increases (Stern, 2007). To appreciate the scale of this scenario, it is sufficient to note that an average global temperature increase of between 3ºC and 4ºC would very likely involve the partial collapse of the Amazon (Hepburn and Stern, 2008).

The economic costs of climate-change mitigation processes include the costs of reducing emissions produced by the use of fossil-based energy and fuels, or changes in land use. The magnitude of these costs depends on the amount by which emissions are to be cut, the time period and the time path chosen for the reduction, and even the specific place in which the mitigation process will be deployed. Mitigation targets proposed internationally involve different efforts and paths that could also be differentiated by countries and regions.[8] Thus, to reduce emissions by between 450 and 500 ppm involves cutting current emissions by roughly 50% by 2050 (see figure 3). The scale of this target can be appreciated by considering that total annual emissions are currently between 40 and 50 gigatons of CO_2 equivalent ($GtCO_2e$).[9] With a world population of 6 billion, this means an average of roughly 7 tons per capita (Hepburn and Stern,

[6] Parts per million (ppm) is the measurement unit in which a number of air pollutants are expressed. It indicates one particulate of a given substance for every 999,999 of another substance.
[7] This involves an expected temperature increase of 2º C, in addition to other climate effects.
[8] See, for example, the documents for the 15th International Conference on Climate Change held in Copenhagen on December 2009.
[9] $GtCO_2e$: gigaton of carbon equivalent. One gigaton of CO_2 is equivalent to 1,000 million tons.

TABLE 3

Probabilities of attaining selected average temperature increases

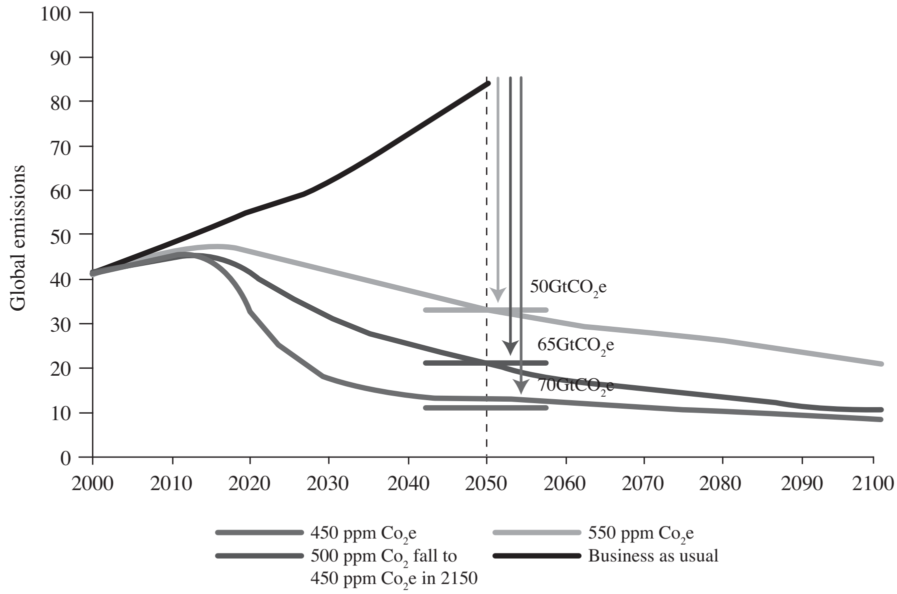
(Percentages)

Stabilization level (ppm CO_2e)	2ºC	3ºC	4ºC	5ºC	6ºC	7ºC
450	78	18	3	1	0	0
500	96	44	11	3	1	0
550	99	69	24	7	2	1
650	100	94	58	24	9	4
750	100	99	82	47	22	9

Source: Hadley Centre: J.M. Murphy and others, "Quantification of modelling uncertainties in a large ensemble of climate change simulations", *Nature*, vol. 430, New York, Nature Publishing Group, 2004.
Note: ppm CO_2e means parts per million of CO_2 equivalent.

FIGURE 3

Stabilization paths and emissions under the business-as-usual (BAU) scenario for 450-550 ppm CO_2e



Source: Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007. The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, Cambridge University Press, September 2007.
Notes: (i) ppm CO_2e means parts per million of CO_2 equivalent. (ii) $GtCO_2e$: Gigatons of carbon equivalent.

2008); so a 50% reduction means reaching a total emissions level of 20 $GtCO_2e$ by 2050, which, with an estimated population of 9 billion inhabitants, is just over 2 tons per capita (Hepburn and Stern, 2008). This entails reducing emissions by between 70% and 75% per unit of output in developed countries and setting specific mitigation targets, albeit naturally, less stringent ones, for the other countries of the world. The above is based on the historical principle of shared, but differentiated, responsibility.

Setting emissions reduction targets to be attained by 2050 and 2100, for all Latin American and Caribbean countries, poses a significant challenge. Naturally, there are ethical issues to be considered, for while the region has not historically contributed to the stock of greenhouse gas emissions, it suffers a major part of the repercussions of climate change. Moreover, the region's adaptation capacities are less than those of developed countries, given its per capita income levels. Nonetheless, future international mitigation agreements are bound to include some type of binding commitment for Latin American and Caribbean countries.

It is therefore is important to identify the main characteristics of greenhouse gas emissions in the region:

— Greenhouse gas emissions from Latin America and the Caribbean currently represent a small proportion of total global emissions; and they actually declined between 1990 and 2000.[10,11] The South American share of emissions dropped from

[10] Greenhouse gas emissions are expressed in CO_2 equivalent, using the 100-year global warming potentials contained in the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 1996). The greenhouse gases included are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and gases with high global warming potential: hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6). According to the country reports filed submitted to the United Nations framework Convention on Climate Change, they encompass the energy sectors, industrial processes, agriculture, changes in land use and forests and waste. The energy sector is subdivided into electricity and heating, transport, manufacture and construction, other types of fuel burning and escaped gases (ECLAC, 2009a).

[11] The database used for emissions is that of the World Resources Institute, which allows for historical comparisons between countries.

11.5% of the total in 1990 to 9.7% in 2000; while Central America's contribution decreased from 0.94% to 0.71%, and the Caribbean share increased marginally from 0.28% to 0.30% (see figure 4). These figures reveal two contrasting trends in Latin America and the Caribbean: a continuous rise in emissions from energy consumption and cement production, and a recent overall reduction in the trend of emissions arising mainly from changes in land use (ECLAC, 2009a).

— The composition of emissions in Latin America and the Caribbean, compared to the world average, shows a smaller energy-component share and greater importance of emissions associated with changes in land use (ECLAC, 2009a). Nonetheless, this could change in the future if current trends in terms of larger emissions from fossil-fuel energy consumption are maintained, and if emissions associated with changes in land use are brought under control (see figure 4) (ECLAC, 2009a).

— Total emissions by individual countries are concentrated fundamentally in Brazil and Mexico, the Bolivarian Republic of Venezuela, Argentina, Peru and Colombia (ECLAC, 2009a).

— Total emissions per capita across the region are highly heterogeneous, although generally below the world average (ECLAC, 2009a).

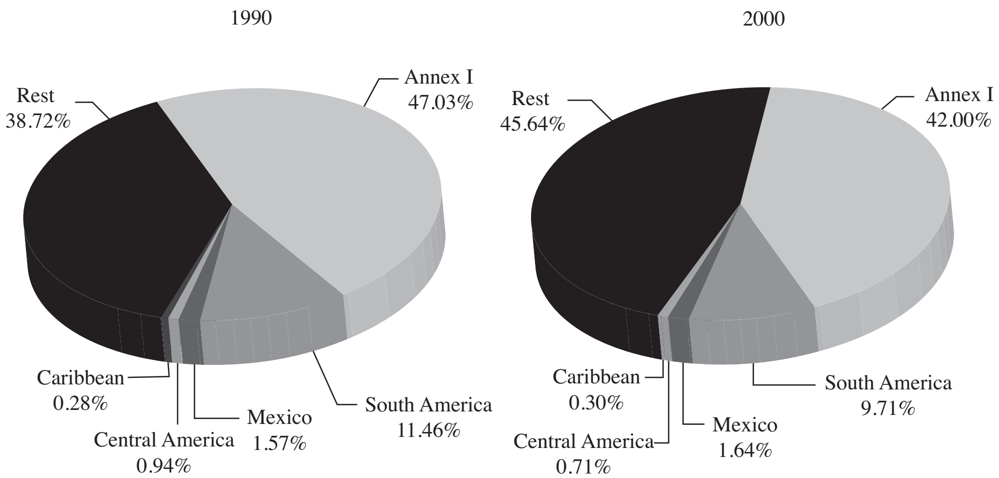
— Greenhouse-gas emissions originating in the energy and cement sectors in Latin America and the Caribbean still represent a small share of total global emissions, despite growing continuously in recent years (ECLAC, 2009a).

This evidence as a whole shows that greenhouse-gas emissions from Latin America and the Caribbean arising from changes in land use should decline further, but emissions from energy consumption are likely to continue their rising trend. Thus, the region's participation in an international mitigation agreement needs to take special account of the trend of emissions linked to energy consumption.

FIGURE 4

Latin America and the Caribbean: Share of total greenhouse gas emissions, including changes in land use, 1990 and 2000

(Percentages)



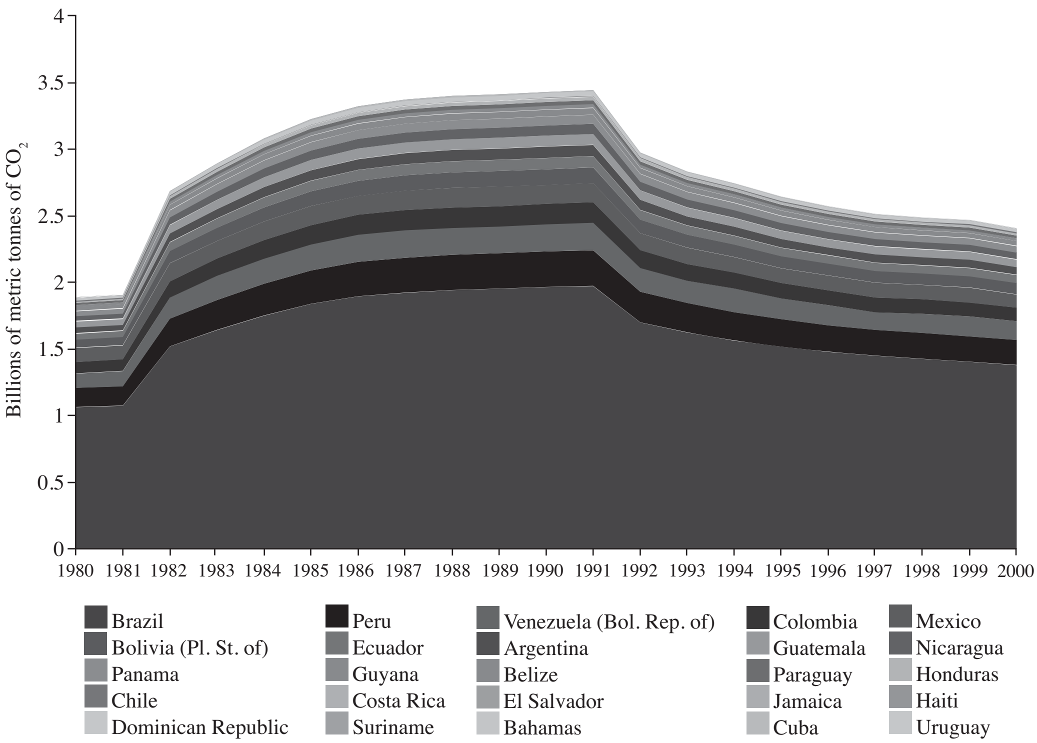
Source: Prepared on the basis of Economic Commission for Latin America and the Caribbean (ECLAC) *Economics of Climate Change in Latin America and the Caribbean: Summary 2009* (LC/G.2425), Santiago, Chile, November 2009; and World Resources Institute (2009), *Climate Analysis Indicators Tool (CAIT)* version 6.0., Washington, D.C., 2009.

Notes: (i) Includes CO_2 (carbon dioxide), NH_4 (ammonia), N_2O (nitrous oxide), PFCs (perfluorocarbons), HFC_s (hydrofluorocarbons), SF_6 (sulphur hexafluoride). (ii) Data on changes in land use are not available for Antigua and Barbuda, Barbados, Dominica, Grenada, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Saint Lucia and Trinidad and Tobago.

FIGURE 5

Latin America and the Caribbean: CO_2 emissions associated with changes in land use, 1980-2000

(Billions of metric tons)



Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009. CO2= Carbon dioxide.

VI

Emissions and energy consumption in Latin America and the Caribbean

The relation between CO_2 emissions and energy consumption and cement production displays several regular patterns,[12] which can be analysed in the context of the well-known Kaya identity (Kaya, 1990) or the IPAT identity (O'Neill and others, 2003; Perman and others, 2003; Yamaji and others, 1991; Bongaarts, 1992).[13] The latter, expressed in equation (5), shows that per capita emissions in each country tend to track per capita GDP trends, the ratio between energy consumption and GDP (energy intensity) and the ratio between CO_2 produced by energy consumption and energy consumption itself (carbon intensity). Thus, in a growing economy it is common for emissions rise in line with GDP per capita.[14] Nonetheless, the possibility of controlling or reducing emissions corresponds to the capacity to reduce energy intensity or the ratio between emissions and energy intensity. Moreover, as

[12] Some of these results are published in ECLAC (2009a).

[13] The IPAT identity is also commonly used with growth rates, and additively, in both absolute and per capita terms. The variables are expressed in logarithmic form and only represent an approximation.

[14] Maintaining a linear relation.

identity (5) shows, energy intensity and the intensity of emissions with respect to energy can be summarized as the intensity of emissions in relation to GDP. Thus, the trend of the two latter terms is fundamental for understanding an economy's mitigation capacity, which is encapsulated in the ratio between emissions and GDP and normally evolves through time.

$$\Delta\left[\frac{CO_2}{POB}\right] = \Delta\left[\frac{GDP}{POB}\right] X \Delta\left[\frac{ENERG}{GDP}\right] X \Delta\left[\frac{CO_2}{ENERG}\right] \quad (5)$$

$$\Delta\left[\frac{CO_2}{GDP}\right] = \Delta\left[\frac{ENERG}{GDP}\right] X \Delta\left[\frac{CO_2}{ENERG}\right] \quad (6)$$

where CO_2 represents CO_2 emissions, GDP is gross domestic product, POB stands for population, and ENERG represents energy consumption. The available evidence on the regional trend of emissions and energy consumption, in the context of the IPAT identity, can be summarized in the following points:[15]

i. For Latin American and Caribbean countries as a whole, CO_2 linked to energy consumption and cement production displays a simple average growth rate of 2.6% for the period 1990-2005 (see figure 6), albeit with significant variations between countries.[16]

ii. Energy consumption in Latin America and the Caribbean is very dynamic, with an simple average growth rate of 3.1% per year, compared to a world average of 2.11% for the period 1970-2007, albeit with different growth rates in individual countries (see figure 7).

iii. There is a positive relation between the trends in per capita emissions, per capita energy consumption, and income per capita (see figures 8 and 9). This reflects the extent to which the economies of Latin American and Caribbean depend on energy consumption, and it underscores the difficulties of achieving an international mitigation agreement that

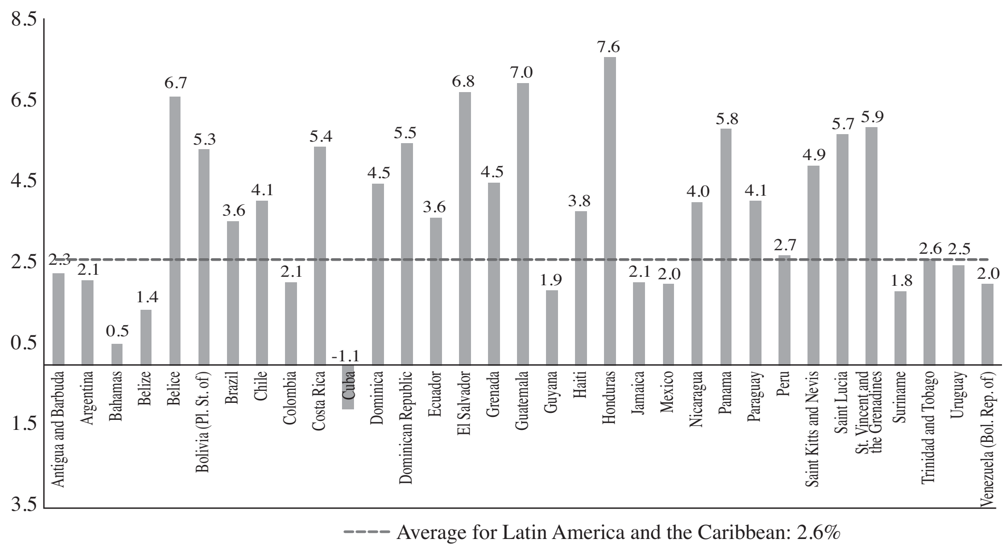
[15] The ECLAC database was used (ECLAC, 2009a).

[16] CO_2 emissions are measured as the mass of carbon dioxide (CO_2) produced during the combustion of solid, liquid and gas fuels, cement manufacture, and the burning of gases. The estimates do not include fuels in the bunkers used international transport. (World Resources Institute, 2009).

FIGURE 6

Latin America and the Caribbean: Annual average growth rate of CO_2e emissions, 1990-2005

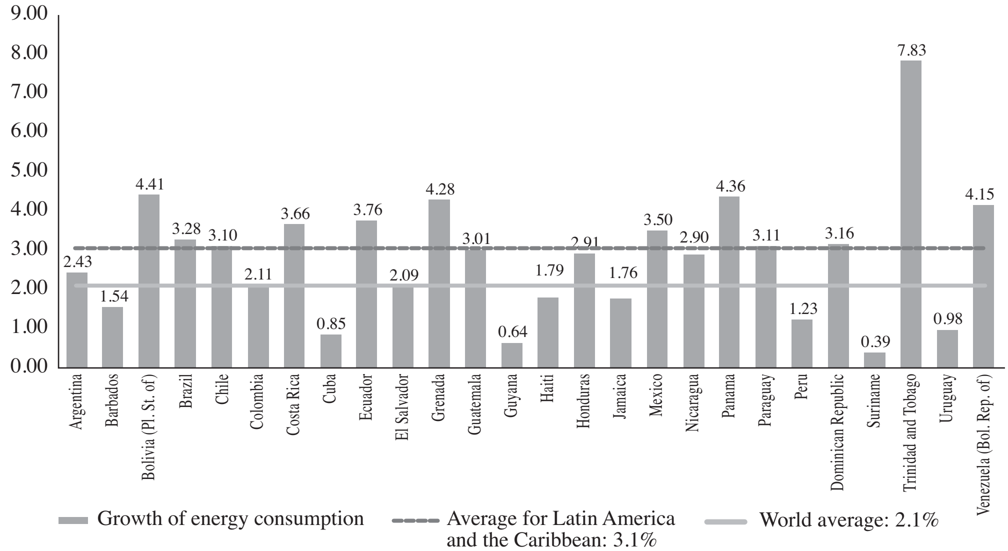
(Percentages)



Source: Economic Commission for Latin America and the Caribbean (ECLAC), using data from World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, [online] www.cait.wri.org.

FIGURE 7

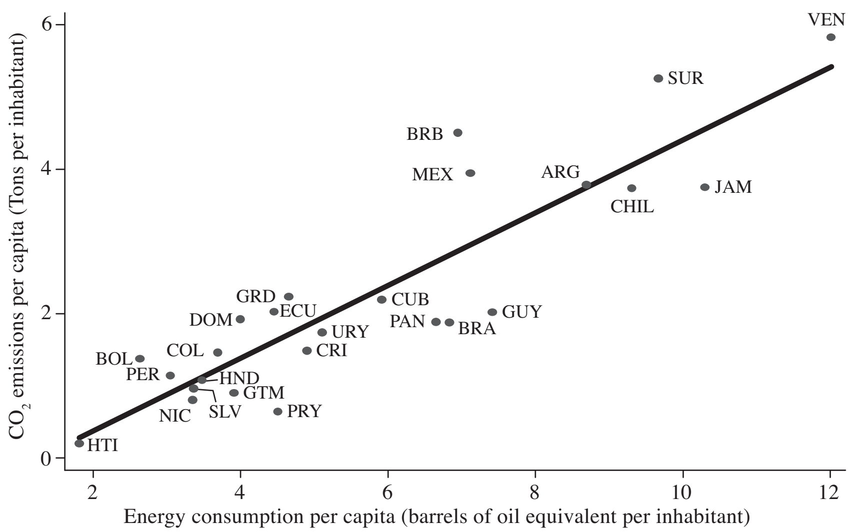
Latin America and the Caribbean: Annual average growth rate of energy consumption, 1970-2007
(Percentages)



Source: Economic Commission for Latin America and the Caribbean (ECLAC), on the basis of information from the Latin American Energy Organization (OLADE) and the Energy Economics Information System (SIEE).
Note: The annual average growth rate for the world is calculated on the basis of data from World Development Indicators, published by the World Bank at www.worldbank.org.

FIGURE 8

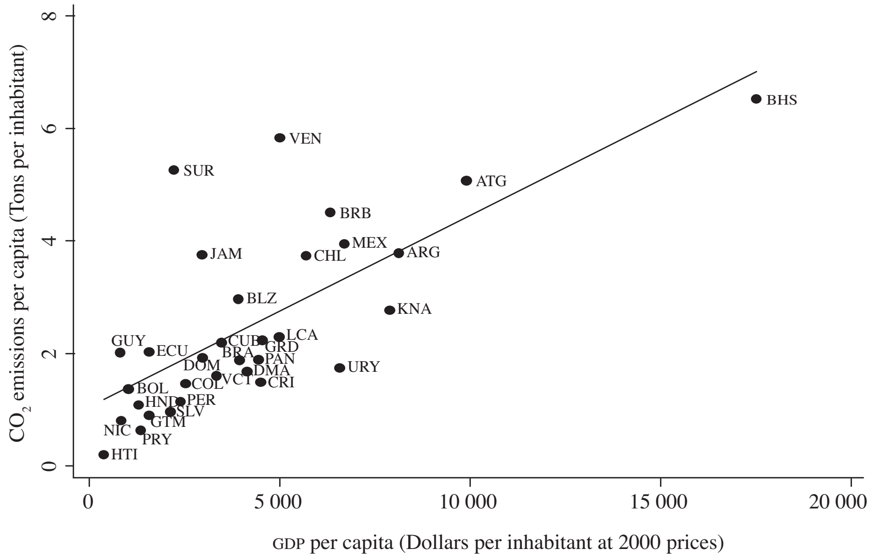
Latin America and the Caribbean: CO_2 emissions per capita and energy consumption per capita in 2005



Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009, using CO_2 emissions of statistics from the World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, Washington, D.C., 2009.
Notes: (i) CO_2: carbon dioxide. (ii) The statistics on total energy consumption were obtained from the Energy Economics Information System (SIEE) of the Latin American Energy Organization (OLADE). (iii) HND: Honduras, GTM: Guatemala, SLV: El Salvador, CRI: Costa Rica, GRD: Grenada, BOL: Plurinational State of Bolivia, DOM: Dominican Republic, CHL: Chile, NIC: Nicaragua, PRY: Paraguay, BRA: Brazil, ECU: Ecuador, PER: Peru, TTO: Trinidad and Tobago, URY: Uruguay, ARG: Argentina, COL: Colombia, JAM: Jamaica, MEX: Mexico, VEN: Bolivarian Republic of Venezuela, GUY: Guyana, SUR: Suriname, BRB: Barbados, CUB: Cuba, HTI: Haiti, PAN: Panama.

FIGURE 9

Latin America and the Caribbean: CO_2 emissions per capita and GDP per capita in 2005



Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009,using statistics on CO_2 emissions from World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, Washington, D.C., 2009.

Notes: (i) The figures for gross domestic product (GDP) at constant 2000 prices were obtained from the ECLAC Economic Indicators and Statistics Database (BADECON). (ii) HND: Honduras, GTM: Guatemala, SLV: El Salvador, CRI: Costa Rica, GRD: Grenada, BOL: Plurinational State of Bolivia, DOM: Dominican Republic, CHL: Chile, NIC: Nicaragua, PRY: Paraguay, BRA: Brazil, ECU: Ecuador, PER: Peru, TTO: Trinidad and Tobago, URY: Uruguay, ARG: Argentina, COL: Colombia, JAM: Jamaica, MEX: Mexico, VEN: Bolivarian Republic of Venezuela, GUY: Guyana, SUR: Suriname, BRB: Barbados, CUB: Cuba, HTI: Haiti, PAN: Panama.

sets specific limits on such consumption for the region (ECLAC, 2009a).

iv. The ratios between energy consumption and per capita GDP by country (Destais, Fouquau and Hurlin, 2007) display an inverse relation with GDP per capita (see figure 10). Thus, higher per capita income normally means less energy intensity with respect to GDP per capita. Nonetheless, this reduction in energy intensity is insufficient to halt the absolute increase in the growth of energy consumption and emissions in the region.

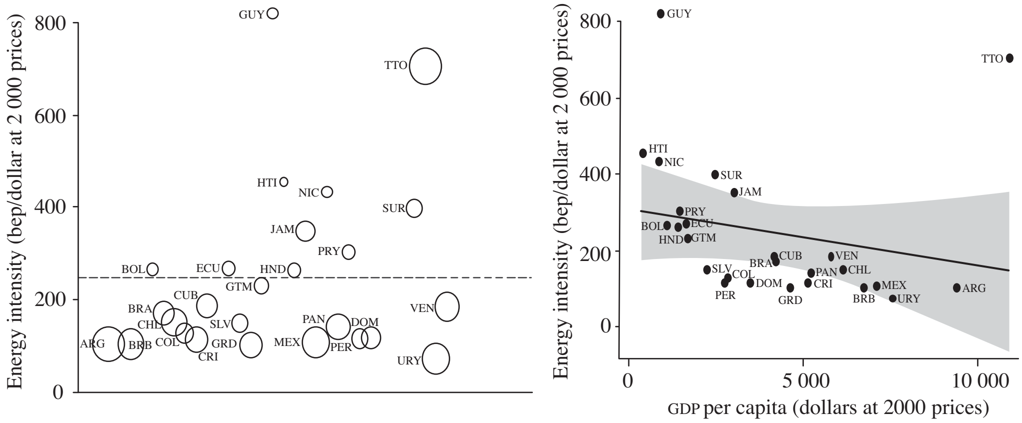
v. In terms of CO_2 intensities in relation to energy, the countries of Latin America and the Caribbean display a mixed trend in the period 1990-2005. In 17 countries, carbon intensity increases: Barbados, the Plurinational State of Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Paraguay, Peru, Suriname and Uruguay; whereas it decreases (decarbonization rate) in Argentina, Chile, Ecuador, Grenada, Haiti, Jamaica, Panama, Trinidad and Tobago, and the Bolivarian Republic of Venezuela (see figure 11).[17] In this context, only in two of the region's countries did energy intensity and carbon intensity simultaneously decline between 1990 and 2005 (ECLAC, 2009a).

vi. Per capita emissions from energy consumption and cement production in Latin America and the Caribbean are still below developed-economy levels, although varying greatly between country; and they are growing fast. This can be seen by simulating per capita emissions in Latin America and the Caribbean in the IPAT identity, considering energy intensity with respect to GDP and CO_2 in relation to energy in other regions of the world (ECLAC, 2009a) (see figure 12). It is thus clear that the emissions that would be generated with an energy matrix similar to China's, for example,

[17] Antigua and Barbuda, Bahamas, Belize, Dominica, Saint Kitts and Nevis, Saint Vincent and the Grenadines and Saint Lucia were not considered because they did not have data available on energy consumption.

FIGURE 10

Latin America and the Caribbean: GDP per capita and energy intensity, 2007



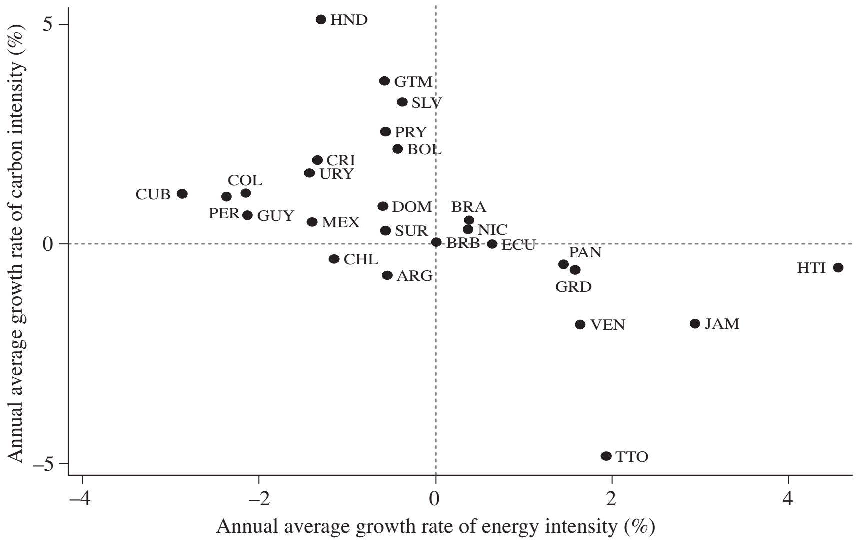
Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009, using total energy consumption statistics from the Energy Economics Information System (SIEE) of the Latin American Energy Organization (OLADE). The shaded area represents the standard deviation.

Notes: (i) The figures for gross domestic product (GDP) per capita at constant 2000 prices were obtained from the ECLAC Economic Indicators and Statistics Database (BADECON). (ii) bep: Barrels of petroleum equivalent, (iii) the size of the circumference is related to the country's GDP per capita. The shaded area represents the standard deviation. (iv GUY: Guyana; TTO: Trinidad and Tobago, HT: Haiti, NIC: Nicaragua, SUR: Suriname, JAM: Jamaica, PRY: Paraguay, BOL: Plurinational State of Bolivia, ECU: Ecuador, HND: Honduras, GTM: Guatemala, SLV: El Salvador, BRA: Brazil, CUB: Cuba, VEN: Bolivarian Republic of Venezuela, PER: Peru, COL: Colombia, DOM: Dominican Republic, PAN: Panama, CHL: Chile, CRI: Costa Rica, GRD: Grenada, BRB: Barbados, MEX: Mexico, URY: Uruguay, ARG: Argentina.

FIGURE 11

Latin America and the Caribbean: Annual average growth rate of energy intensity vs. annual average growth rate of carbon intensity, 1990 - 200

(Percentages)

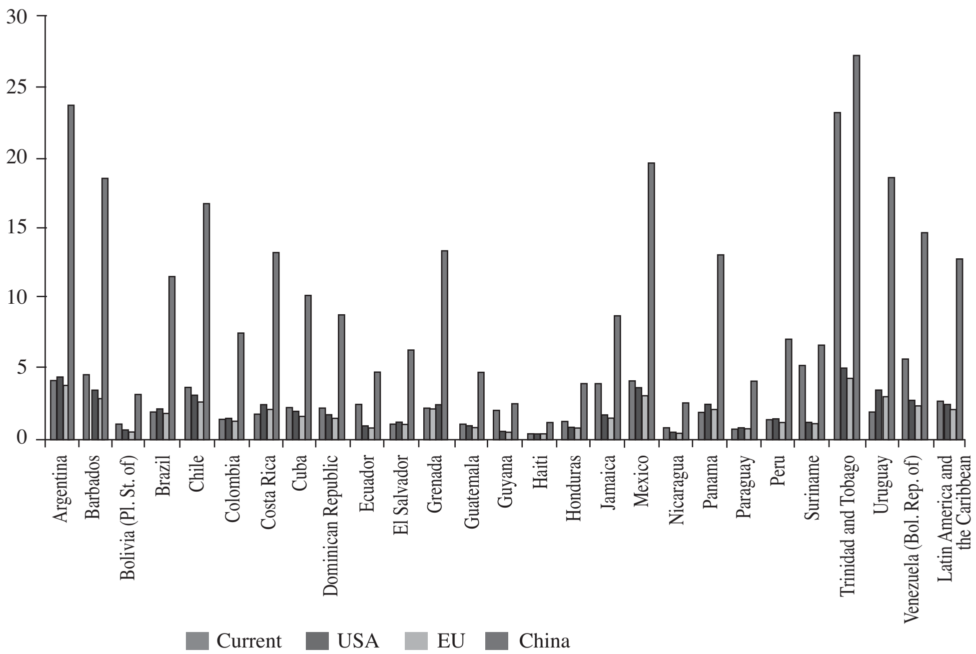


Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009, using total energy consumption statistics from the Energy Economics Information System (SIEE) of the Latin American Energy Organization (OLADE).

Notes: (i) HND: Honduras, GTM: Guatemala, SLV: El Salvador, PRY: Paraguay, BOL: Plurinational State of Bolivia, CRI: Costa Rica, CUB: Cuba, COL: Colombia, URY: Uruguay, PER: Peru, GUY: Guyana, MEX: Mexico, DOM: Dominican Republic, BRA: Brazil, SUR: Suriname, NIC: Nicaragua, BRB: Barbados, ECU: Ecuador, CHL: Chile, ARG: Argentina, PAN: Panama, GRD: Grenada, HTI: Haiti, VEN: Bolivarian Republic of Venezuela, JAM: Jamaica, TTO: Trinidad and Tobago. (ii) The figures for gross domestic product (GDP) per capita at constant 2000 prices were obtained from the ECLAC Economic Indicators and Statistics Database (BADECON).

FIGURE 12

Latin America and the Caribbean: CO_2 emissions per capita using energy and carbon intensity of the United States, the European Union and China



Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009, using total energy consumption statistics from the Energy Economics Information System (SIEE) of the Latin American Energy Organization (OLADE).
Notes: (i) The figures for gross domestic product (GDP) per capita at constant 2000 prices were obtained from the ECLAC Economic Indicators and Statistics Database (BADECON). (ii) Statistics for the United States, the European Union and China were obtained from World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, Washington, D.C., 2009.

are way above current levels in the region. This reflects the use of cleaner energy-generation sources in Latin America and the Caribbean, compared to those of China. Nonetheless, when the region's emissions are simulated on the basis of the ratios between energy and GDP and between emissions and energy in developed countries, the differences are much smaller, and are even negative for some countries. From this standpoint, there is room for manoeuvre in the region which should be exploited; but the situation could deteriorate rapidly.

vii. Emissions per capita in Latin America and the Caribbean display an absolute convergence process, known as β convergence, or convergence in the dispersion of CO_2 per capita emissions (σ convergence) (Barro and Sala-i-Martin, 1992).[18] In other words, per capita emissions in countries with lower per capita emissions are growing faster than those of countries with higher per capita emissions (see figure 13).

viii. The available evidence indicates that per capita emissions are converging in absolute terms across countries, as seen in the estimates based on equation (7), which is commonly used to analyse absolute convergence processes in per capita GDP between countries (Barro and Sala-i-Martin, 1992; Sala-i-Martin, 1996; Durlauf, Johnson and Temple, 2006; Maddala and Wu, 2000).

$$\Delta y_{it} = \alpha_i + \beta y_{i,t-1} + \varphi x_{it} + u_{it} \qquad (7)$$

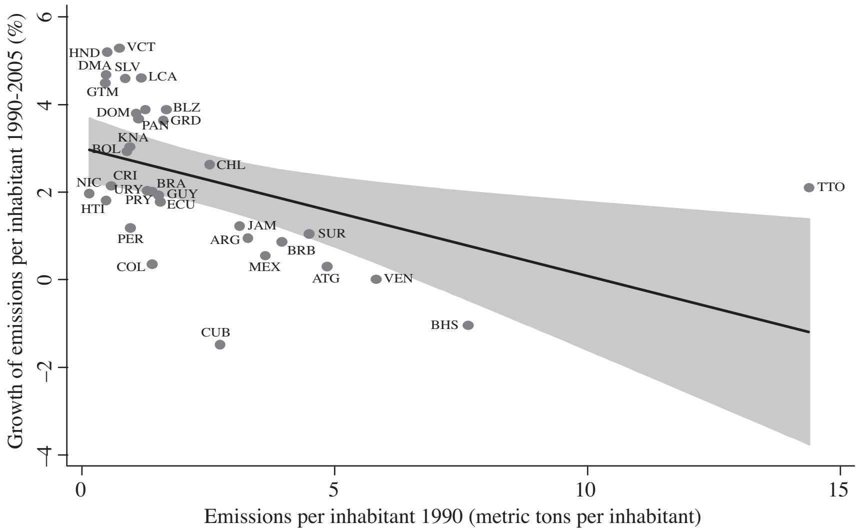
where a coefficient $\beta<0$ indicates an absolute convergence process. The α coefficient captures specific effects by country, and x_{it} represents a set of additional factors, which, if included, make it possible to identify the possible presence of conditional convergence. The

[18] This point is based on the analysis of convergence processes in GDP per capita (Sala-i-Martin, 1996).

FIGURE 13

Latin America and the Caribbean: Emissions per inhabitant and growth of emissions per inhabitant, 1990-2005

(Percentages)



Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009, using CO_2 statistics obtained from World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, Washington, D.C., 2009.

Notes: (i) Population data were obtained from the ECLAC Database on Social Statistics and Indicators (BADEINSO). (ii) The shaded area represents the standard deviation. (iii) HND: Honduras, VCT: Saint Vincent and the Grenadines: Dominica, LCA: Saint Lucia, BLZ: Belize, KNA: Saint Kitts and Nevis: Guatemala, SLV: El Salvador, PRY: Paraguay, BOL: Plurinational State of Bolivia, CRI: Costa Rica, CUB: Cuba, COL: Colombia, URY: Uruguay, PER: Peru, GUY: Guyana, MEX: Mexico, DOM: Dominican Republic, BRA: Brazil, SUR: Suriname, NIC: Nicaragua, BRB: Barbados, ECU: Ecuador, CHL: Chile, ARG: Argentina, PAN: Panama, GRD: Grenada, HTI: Haiti, VEN: Bolivarian Republic of Venezuela, JAM: Jamaica, TTO: Trinidad and Tobago, BHS: Bahamas, ATG: Antigua.

subscript i represents the country and t represents the year in question. The estimation of equation (8) —based on the cross-section database (equation (9)) and panel data (equation (10)) (Wooldridge, 2001; Baltagi, 2008) for the group of Latin American and Caribbean countries in the period 1990-2005— shows that per capita emissions in the region as a whole will increase in the coming decades within an absolute convergence process. The econometric estimations also do not reject the null hypothesis of the Hausman test (Hausman, 1978) in equation (9), so the fixed effects specification is not rejected. Furthermore, the statistical significance of the dummy variables for countries reflects the existence of significant regional differences (Romer, 1989; Barro, 1991). The t-statistics in parentheses are robust to the possible presence of heteroscedasticity (Wooldridge, 2001; Baltagi, 2008).

$$\frac{\log\left[\left(\left[\!\left[\left(CO_2 n\right]\!\right]_{i2005}\right)\right)\right]}{\left(\left[\!\left[CO_2 n\right]\!\right]_{i1990}\right)} = 0.40 - 0.15 * \log\left(CO_2 n_{i1990}\right) + u_i \qquad (8)$$

(9.90) (-3.99)

$$\frac{\log\left[\left[\!\left[\left(CO_2 n\right]\!\right]_{it}\right)\right]}{\left(\left[\!\left[CO_2 n\right]\!\right]_{it-1}\right)} = 0.16 - 0.23 * \log\left(CO_2 n_{it-1}\right) + u_i \qquad x^2(1) = 71.50(0.00) \qquad (9)$$

(2.19) (-2.04)

ix. There is an inverse relation between the rate of decoupling of emissions and GDP and the rate of growth of per capita GDP (Vivid Economics, 2009). In other words, countries with a faster growing GDP per capita are also those that reduce their emissions per unit of GDP most aggressively (see figure 14). This shows that a high rate of economic growth is not necessarily inconsistent with the capacity to reduce emissions per unit of output. So it is possible, within certain ranges, to reconcile dynamic economic growth with a transition to a lower carbon economy, although the pace of reduction is still insufficient to contain emissions in absolute terms (ECLAC, 2009a).

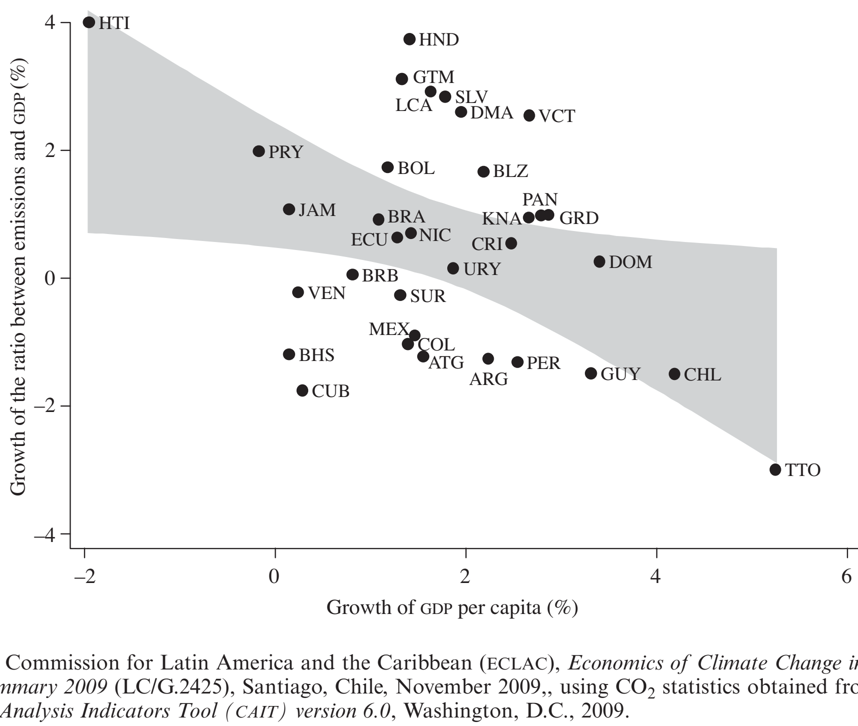
x. CO_2 emissions caused by energy consumption and cement production can projected using the IPAT identity.[19] The set of simulations performed (Samaniego and Galindo, 2009) in the BAU scenario shows that it is highly likely that greenhouse gas emissions linked to energy consumption and cement production will continue to rise in Latin America and the Caribbean. Specifically, the region's CO_2 emissions per capita could grow at a simple average rate of around 2%

[19] These simulations assume A trend GDP per capita growth are estimated with or autoregressive integrated moving average (ARIMA) models and data on population growth from the Latin American and Caribbean Demography Centre (CELADE) - Population Division of the United Nations, and assuming for each country its historical average growth rate of energy and carbon intensity (ECLAC, 2009a).

FIGURE 14

Latin America and the Caribbean: GDP growth and the rate of decoupling between CO_2 emissions and GDP, 1990-2005

(Percentages)



Source: Economic Commission for Latin America and the Caribbean (ECLAC), *Economics of Climate Change in Latin America and the Caribbean. Summary 2009* (LC/G.2425), Santiago, Chile, November 2009,, using CO_2 statistics obtained from World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, Washington, D.C., 2009.

Notes: (i) The shaded area represents the standard deviation. (ii) The decoupling rate is defined as the inverse of the rate of growth of the ratio between CO_2 emissions and GDP, in other words a reduction (increase) of this ratio means an increase (decrease) in the decoupling rate. (iii) Data on gross domestic product (GDP) per capita at constant 2000 prices were obtained from the ECLAC Economic Indicators and Statistics Database (BADECON). (iv) Population data were obtained from the ECLAC Database on Social Statistics and Indicators (BADEINSO). (v) HND: Honduras, VCT: Saint Vincent and the Grenadines: Dominica, LCA: Saint Lucia, BLZ: Belize, KNA: Saint Kitts and Nevis: Guatemala, SLV: El Salvador, PRY: Paraguay, BOL: Plurinational State of Bolivia, CRI: Costa Rica, CUB: Cuba, COL: Colombia, URY: Uruguay, PER: Peru, GUY: Guyana, MEX: Mexico, DOM: Dominican Republic, BRA: Brazil, SUR: Suriname, NIC: Nicaragua, BRB: Barbados, ECU: Ecuador, CHL: Chile, ARG: Argentina, PAN: Panama, GRD: Grenada, HTI: Haiti, VEN: Bolivarian Republic of Venezuela, JAM: Jamaica, TTO: Trinidad and Tobago, BHS: Bahamas, ATG: Antigua.

per year under a BAU scenario. This is the result of the process of emissions convergence in absolute terms and the historical trends of energy intensity with respect to GDP and of emissions in relation to energy in the region.

These simulations show that economic growth in Latin America and the Caribbean will be accompanied by an increase in CO_2 emissions from energy consumption and cement production; but there will also be a relatively gradual process whereby emissions become decoupled from trend GDP. This can be explained by a development strategy that combines higher levels of income per capita with higher productivity and the control or reduction of emissions.

VII

Emissions per capita and income per capita: some regularities

Emissions from energy consumption and cement production per unit of GDP are different for each of the countries of Latin America and the Caribbean, although they are generally below the world average (see figure 15). In addition, the response or sensitivity of the rate of emissions with regard to income in the face of changes in GDP per capita differs across countries and displays complex and non-dynamic behaviour patterns (see figure 16). These changes in response sensitivities between emissions and GDP and GDP per capita could be related to various factors, such as changes in the composition of the productive structure (the hypothesis proposed by Linder, 1961), changes in relative prices, technological innovation processes, more efficient development of economies and the imposition of more stringent regulations (Gupta and others, 1997). This could correspond, generically, to a type of environmental Kuznets curve (Kuznets, 1955; Grossman and Krueger, 1995; Torras and Boyce, 1998; Selden and Song, 1994; McConnell, 1997; Rothman and de Bruyn, 1998) or a V-shaped curve, where economic growth is accompanied by gradual environmental improvements following an initial deterioration.[20] Thus, under the Kuznetz hypothesis, or V-shaped curve, the intensity of emissions with respect to GDP per capita increases in the initial stages of economic development, before reaching a peak and then gradually declining (Rothman, 1998; Stern, Common and Barbier, 1996; Ekins, 1997).[21]

The presence of a V-shaped relation or inverted Kuznetz curve can be obtained by assuming, firstly, that per capita emissions are a direct function of output per capita, or that per capita emissions remain constant according to the coefficient ϕ_1:

$$EMPC_{it} = \phi_o + \phi_1 YPC_t + u_t \tag{10}$$

where $EMPC_t$ are emissions per capita, YPC_t is output per capita and ϕ_1 is the coefficient associated with emissions. Assuming then that the coefficient that relates emissions to income per capita is also a function of income per capita, the following relation is obtained:

$$\phi_1 = \phi_2 + \phi_3 YPC_t \tag{11}$$

Substituting equation (11) in (10) gives:

$$\begin{aligned} EMPC_{it} = \phi_o + (\phi_2 + \phi_3 YPC_t)YPC_t + u_t = \\ \phi_2 YPC_t + \phi_3 YPC^2{}_t + u_t \end{aligned} \tag{12}$$

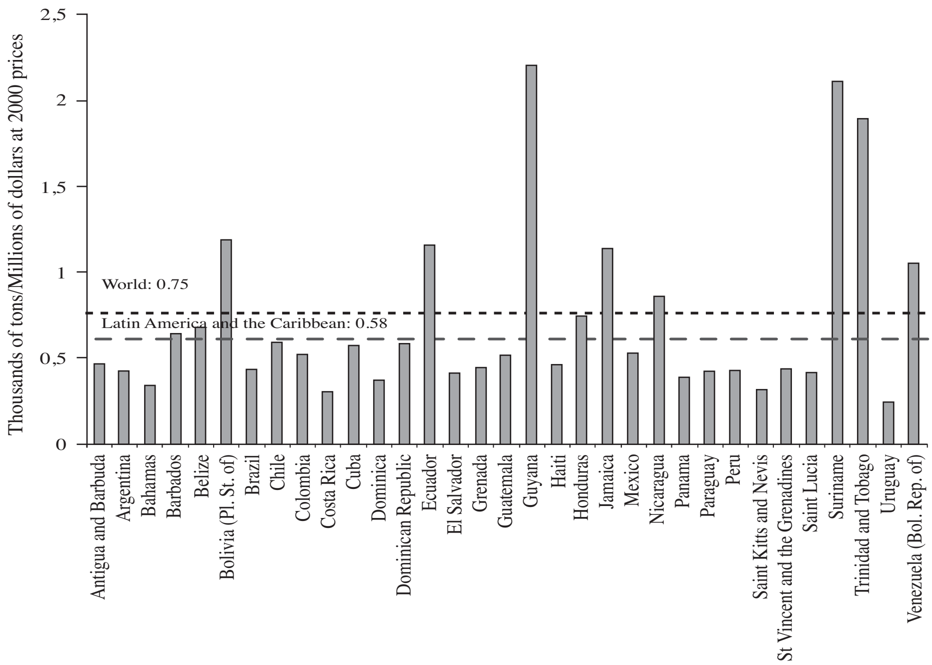
Equation (12) shows that emissions are sensitive to variables that include an income per capita squared term, which generates a nonlinear effect of the reduction of emission intensities. The Kuznets curve

[20] The V-shape can be obtained, for example, from an overlapping generations model (John and Pecchenino, 1994), or an optimization model (Stokey, 1998) or else from a constrained consumer preferences model (Jaeger, 1998).

[21] The economic causes of this behaviour are grouped, in the context of the Kuznetz curve, in three effects: scale, composition and technology (Rothman, 1998; Stern, Common and Barbier, 1996; Ekins, 1997; Grossman and Krueger, 1995).

FIGURE 15

Latin America and the Caribbean: CO_2 emissions per unit of GDP, 2005



Source: Prepared by the Economic Commission for Latin America and the Caribbean (ECLAC), using CO_2 statistics obtained from World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, Washington, D.C 2009.
Notes: (i) Data on gross domestic product (GDP) per capita at constant 2000 prices were obtained from the ECLAC Economic Indicators and Statistics Database (BADECON). (ii) Population data were obtained from the ECLAC Database on Social Statistics and Indicators (BADEINSO).

then represents a reduced form that reflects extremely complex processes that lead to nonlinear effects.[22]

Thus, initially, the intensity of emissions per capita with respect to GDP per capita can be estimated econometrically under a linear specification (Ang, 1987; Zilberfarb and Adams, 1981; Shrestha, 2000), for panel data (Wooldridge, 2001; Baltagi, 2008) such as:

$$empc_{it} = \beta_0 + \beta_1 ypc_{it} + u_{it} \qquad (13)$$

where the lowercase variables represent the natural logarithm of the series. The presence of changes in the intensity of emissions with respect to GDP per capita over time, combined with non-linear effects, can be included in a quadratic reduced form that could correspond to the hypothesis of the Kuznetz curve (Judson, Schmalensee and Stoker, 1999; Destais, Fouquau and Hurlin, 2007):

$$empc_{it} = \beta_0 + \beta_1 ypc_{it} + \beta_2 ypc_{it}^2 + u_{it} \qquad (14)$$

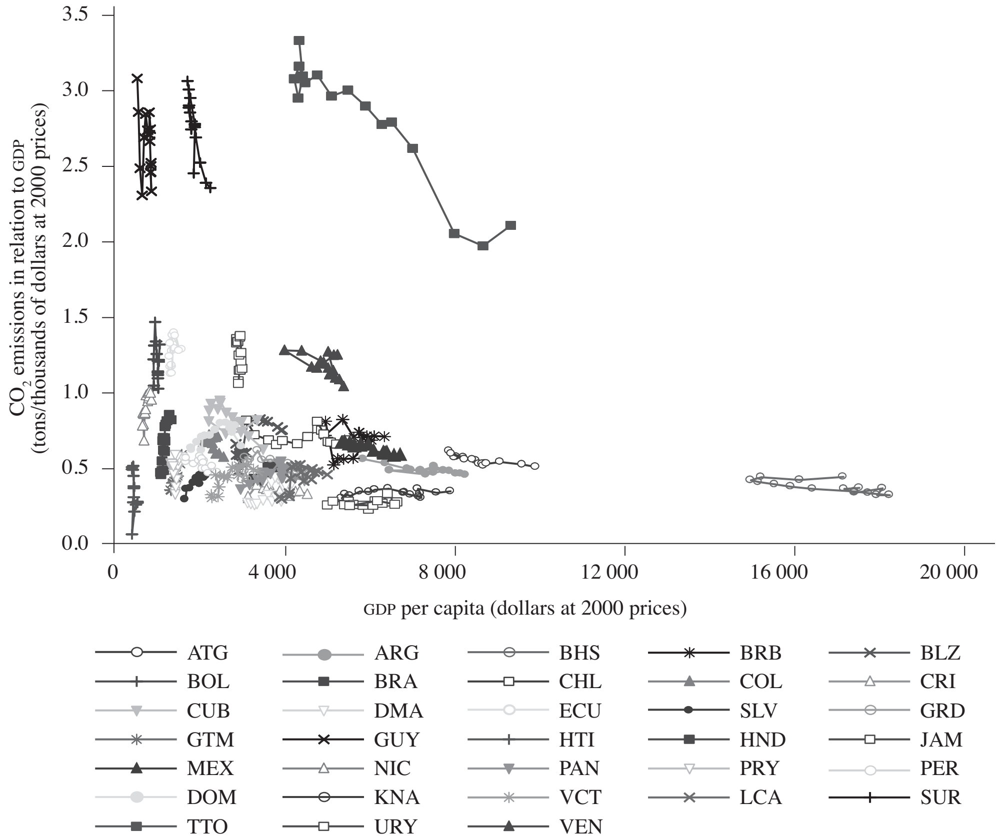
In this way, the non-linear effects were obtained with a β_2 coefficient that is smaller, in absolute terms, than β_1, and negative, because when income per capita increases, this coefficient becomes more important. This type of specification can either assume that all parameters are the same, or else consider changes by country or types of country, using panel estimation through the fixed or random effects method. Nonetheless, in this type of model it is only possible to incorporate differences in the constant term.

To incorporate changes in the parameters over time a Panel Smooth Threshold Regression (PSTR) model can be used (González, Teräsvirta and van

[22] The variables included are only *proxies*, so there could be a problem of omitted variables. (Torras and Boyce, 1998).

FIGURE 16

Latin America and the Caribbean: GDP per capita and CO_2 emissions with respect to GDP



Source: Prepared by the Economic Commission for Latin America and the Caribbean (ECLAC), using CO_2 statistics obtained from World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, Washington, D.C 2009.

Notes: (i) Data on gross domestic product (GDP) per capita at constant 2000 prices were obtained from the ECLAC Economic Indicators and Statistics Database (BADECON). (ii) Population data were obtained from the ECLAC Database on Social Statistics and Indicators (BADEINSO). (iii) ATG: Antigua, BOL: Est. Plurinational State of Bolivia, CUB: Cuba, GTM: Guatemala, MEX: Mexico, DOM: Dominican Republic, TTO: Trinidad and Tobago, ARG: Argentina, BRA: Brazil, DMA: Dominica, GUY: Guyana, NIC: Nicaragua, KNA: Saint Kitts and Nevis, URY: Uruguay, BHS: Bahamas, BHS: Bahamas, CHL: Chile, ECU: Ecuador, HTI: Haiti, PAN: Panama, VCT: Saint Vincent and the Grenadines: VEN: Bolivarian Republic of Venezuela, BRB: Barbados, COL: Colombia, SLV: El Salvador, HND: Honduras, PRY: Paraguay, LCA: Saint Lucia, BLZ: Belize, CRI: Costa Rica, GRD: Granada, JAM: Jamaica, PER: Peru, SUR: Suriname.

Dijk, 2005; Granger and Teräsvirta, 1993; Teräsvirta, 1994).[23] In this model, the response sensitivities are changed when they pass a certain limit and can transit smoothly to the other regime (Aslanidis and Xepapadeas, 2006). This model for emissions per capita with just two regimes and a single transition function can be specified as follows (Destais, Fouquau and Hurlin, 2007):

$$empc_{it} = \beta_0 + \beta_1 y_{it} + \beta_2 y_{it} g\left(ypc_{it}\gamma, c\right) + u_{it} \qquad (15)$$

[23] The model is generalized in Destais, Fouquau and Hurlin, 2007.

In this case, the transition function g(ypc_{it}, γ, c) is continuous and bounded by the threshold variable defined by ypc_{it}, with γ, c as parameters. The PSTR model for CO_2 emissions per inhabitant and for income per capita specify the logistic transition function (González, Teräsvirta and van Dijk, 2005; Granger and Teräsvirta, 1993; Teräsvirta, 1994) as:

$$g\left(ypc_{it};\gamma,c\right) = \left[1+\exp\left(-\gamma\prod_{z=1}^{m} ypc_{it} - c_z\right)\right]^{-1} \qquad (16)$$

where the vector $c = (c_1,\ldots,c_n)'$ denotes an n-dimensional vector of location parameters, and the parameter γ is the gradient of the transition function that determines the smoothness or speed of regime change in the value of the logistic function. In extreme cases, the PTSR model allows the change of regime to be abrupt (Hansen, 1999). This specification makes it possible to identify two regimes, one for when the transition variable is either below the first threshold or above the second threshold; and the other for when the transition variable lies between the two thresholds. The model can thus be interpreted as an inverted Kuznets curve, where a low elasticity is expected at low per capita income levels, but when income per capita rises, elasticity also increases up to a maximum before falling back again. The calculation method initially eliminates the means of individual effects (the u_{it} terms) and then estimates the non-linear least squares model using a standard parameter search procedure (Aslanidis and Xepapadeas, 2006):[24]

The estimations summarized in equation 18 show that elasticity is low when income per capita is below the first threshold (US$ 936 [=antilog(6,84)]) and again when it is above the second threshold of US$ 3 848 [=antilog(8.24)].[25] In both cases, the elasticity is greater (t-statistics in brackets):

$$CO_2n_{it} = 1.31y_{it} - 0.05y_{it}g\left(y_{it}, 3.81; 6.84; 8.24\right) + u_{it} \quad R^2 = 0.62 \tag{17}$$

(41.46) (-9.84) (1.70) (30.41) (20.44)

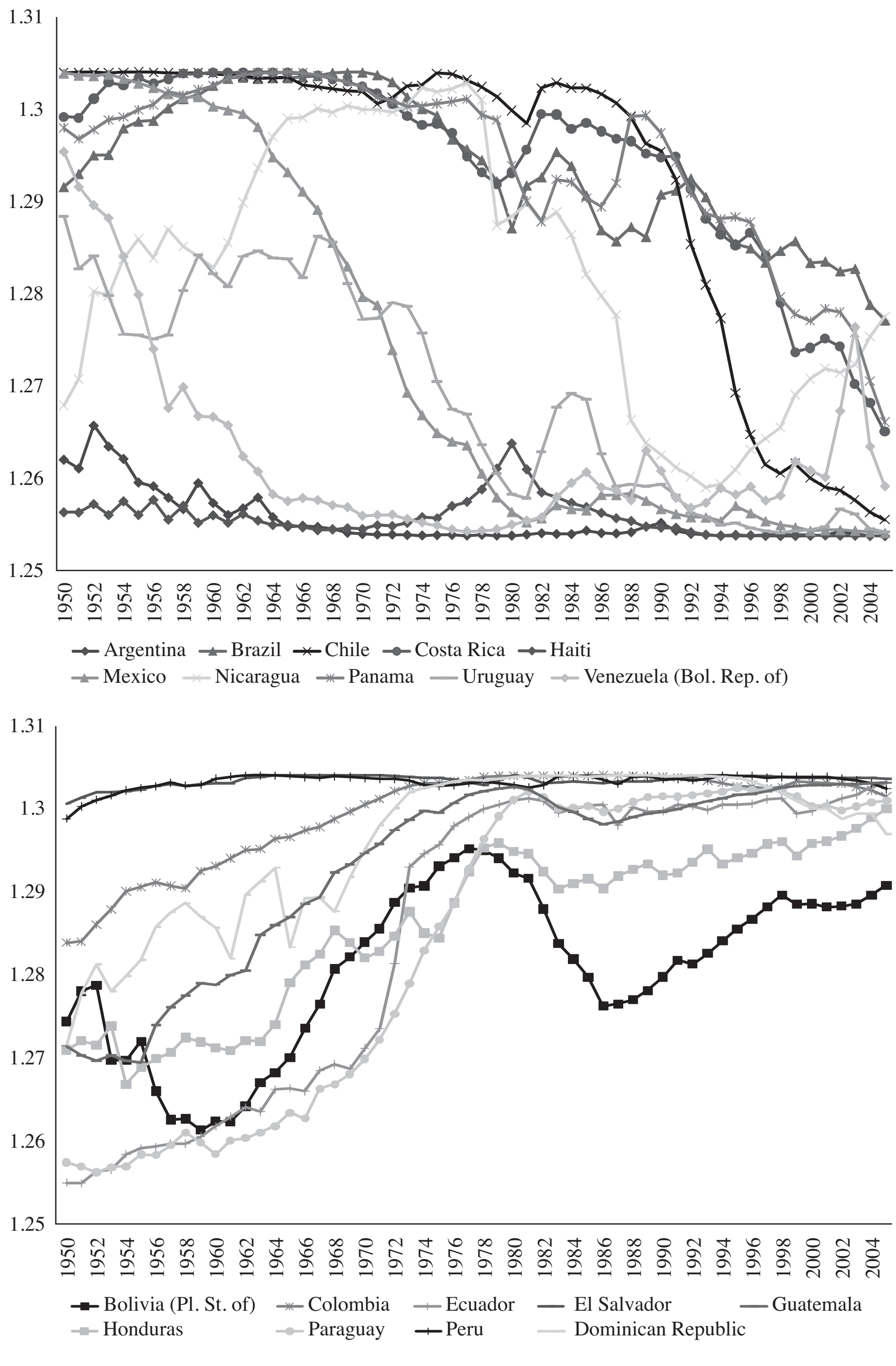
The dynamic of the elasticities is illustrated in figure 17, which divides the countries into two panels. The first contains countries where elasticity has declined, which assumes that they are at a either very low or very high development level by regional standards. For example, both Argentina and Haiti have the lowest elasticities —because Argentina was above US$ 3 848 per capita throughout the period, whereas Haiti did not achieve US$ 936 per capita. The other countries start with income per capita above US$ 936 but below US$ 3 848, but surpass the latter threshold in the 1970s; so elasticity, which was initially high, starts to fall, to reach minimum levels in the 1990s. Lastly, Nicaragua's per capita income is more than double the first threshold, but has not yet passed the second. The second panel includes countries whose elasticity has increased, because they are above the first threshold, but below the second. For example, the Plurinational State of Bolivia and Honduras both started the sample period with per capita incomes below US$ 936; and when they surpass this level elasticity rises and stays high because they have not reached the US$ 3848 threshold. Thus, depending on their initial per capita income, as countries grow, the elasticity of their CO_2 emissions per capita increases with respect to GDP per capita. When they reach a certain development level, however, the trend goes into reverse. This makes it possible to explain the presence of the absolute convergence process in emissions per capita, and suggests an explanation for the non-linear trend of the response sensitivities of per capita emissions with respect to income per capita.

The smooth transition autoregressive (STAR) model thus makes it possible to identify the presence of non-linear behaviour in the response sensitivities of emissions with respect to income per capita, which is consistent with earlier studies that claimed the presence of a V-shaped relation or inverted Kuznets curve (Aslanidis and Xepapadeas, 2006; Grossman and Krueger, 1995; Torras and Boyce, 1998; Selden and Song, 1994; McConnell, 1997; Rothman and de Bruyn, 1998; Rothman, 1998; Stern, Common and Barbier, 1996; Ekins, 1997). This suggests that economic growth is not incompatible with a simultaneous process of emissions reduction. Nonetheless, it needs to be recognized that the current pace of emissions reduction is still unsustainable in relation to any reasonable target for keeping global warming below a 2ºC temperature increase.

[24] The estimations can be found in Teräsvirta (1994); González, Teräsvirta and van Dijk (2005); Hansen (1999).
[25] GDP per capita is obtained from the ECLAC Economic Indicators and Statistics Database (BADECON).

FIGURE 17

Central America and South America: Elasticity of CO_2 emissions per inhabitant with respect to income per capita, 1950-2005



Source: Prepared by ECLAC using CO_2 statistics obtained from World Resources Institute, *Climate Analysis Indicators Tool (CAIT) version 6.0*, Washington, D.C., 2009.

Notes: (i) data on gross domestic product (GDP) per capita at constant 2000 prices were obtained from the ECLAC Economic Indicators and Statistics Database (BADECON). (ii) Population data were obtained from the ECLAC Database on Social Statistics and Indicators (BADEINSO).

VII
Conclusions

Climate change is the result of a set of anthropogenic activities that are closely related to economic activities. In economic terms, climate is a public good, so climate change is a global negative externality (Stern, 2007). Consequently, any strategy to solve the problem, and the public policies to be applied, need to have solid economic foundations.

The available evidence shows that the climate changes observed in Latin America and the Caribbean have substantial economic repercussions on various economic activities. Nonetheless, the costs are heterogeneous (there even temporary gains in some cases) and non-linear; and there are specific thresholds beyond which irreversible losses occur. There is also is a positive relation between the trends of per capita emissions, per capita energy consumption and income per capita. This is consistent with the international evidence (Stern, 2007) and suggests the need to substantially alter the current development strategy to move on to a sustainable development path.

In this regard, projections suggest that per capita emissions will continue to grow regionwide, with the rates for individual Latin American and Caribbean countries converging in absolute terms. Beyond a certain level of per capita income, however, the increase will be less, both in emissions arising from changes in land use and in those caused by energy consumption and cement production. In other words, emissions gradually become decoupled from economic activity beyond certain level of income per capita. In particular, the economic estimations show that the response sensitivities of emissions caused by energy consumption and cement production are low when per capita income is also low. Then, once a certain threshold has been passed, the response sensitivities increase, before gradually falling back again. Nonetheless, these reductions are not sufficient to contain the absolute increase in emissions.

As a whole, the results show that climate change is an additional constraint on the region's economic growth; but it is possible, within certain ranges, to reconcile economic growth with a transition to a low-carbon economy. Building this strategy is a complex task, involving keen debate (Stern, 2007; Nordhaus, 2008; Nordhaus and Boyer, 2000; Pearce and others, 1996; Mendelsohn and Neumann, 1999; Tol, 2002). It has major public-policy consequences, and also raises political, ethical, and international-policy issues concerning the distribution of the costs between countries, with emphasis on adaptation and vulnerability, or on mitigation and compliance mechanisms and the respective sanctions (see, for example, *Oxford Economic Review of Economic Policy*, 2008).

The construction of a strategy to transit to a low-carbon development path should not be seen as an alternative to economic growth. On the contrary, climate change is already putting an additional constraint on that growth. Nonetheless, the transition to a low-carbon economy is an extremely complex process that involves substantive changes in economic development styles.

(Original: Spanish)

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