Climate Change Mitigation and

Institutions for Sustainable Development

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Introduction

Global security and sustainability in the XXIst century depends on reducing dramatically the carbon content of economic activity in the next few decades. However, the world lacks an effective institutional framework to address global warming. While the Kyoto Protocol falls short of providing a workable solution even if its goals are attained, the last effort to update it, the Bali Conference on Climate Change in late 2007, failed to harness a clear global greenhouse-gases (GHG) mitigation schedule.

Stabilization of greenhouse-gases (GHG) emissions is one angle of the broader issue of sustainable economic development. In a nutshell, climate warming is the result of a human interference with the biosphere's ability to recycle greenhouse gases. These gases circulate inside the biosphere through a set of physical, chemical and biological processes that regulate their volume in the atmosphere. Humans produce only a small percentage of the total emitted GHG. By burning fossil fuels and reducing CO_2 absorption through deforestation, economic activity seriously disrupts the balance of those natural processes, producing a net gain in the atmospheric concentration of these gases. Anthropogenic global warming illustrates the enormous physical unbalances produced by our civilization and

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poses the problem of globally managing a free-access good in rapid process of exhaustion, and the possibilities of continuing with economic growth in a world of finite resources.

Dealing successfully with climate change implies fundamentally two things. First, it requires reaching international consensus about differentiated mitigation schedules (i. e., a framework for regulating emission quotas). Second, it demands generating effective mechanisms at the national level for attaining those schedules.

In this paper we examine the nature of the GHG stabilization problem and assess the limits of proposed market-based solutions. We argue that carbon trading is not an effective tool for addressing the problem of global warming, given the magnitude, speed, and complexity of the structural change required for global mitigation. In particular, we argue that carbon trading: a) implies an unjust privatization of the use of the atmosphere; b) it is based on flawed economic theory, and c) will deliver poor results in fostering systemic innovation towards a low-carbon economic structure.

Stabilizing the greenhouse: facts and trends

Global emissions greenhouse-gas (GHG) are accelerating, and with them the potential of global warming. Since the year 2000 global emissions have been growing far more rapidly than the worst scenarios projected by the Intergovernmental Panel on Climate Change (IPCC; see Rogner et al., 2007, and Raupach, et al., 2007). Carbon Dioxide (CO_2) concentration in the atmosphere has increased from ca. 280 parts per million (ppm) in 1750 to 379 ppm in 2005. The growth rate of CO_2 concentration augmented from 6.4 Giga-tons per year in the 1990's to 7.2 Giga-tons per year in the period 2000-2005. If the trend of the last 20 years' continues, human GHG emissions would increase between 40% and 60%

from 2000 to 2050, which will very likely produce an increase of between 2.5 and 4.5°C in the Earth's mean temperature with respect to the year 2000 (Rogner, et al. 2007).

Such apparently small changes in the mean global surface temperature will provoke profound and irreversible changes in climate patterns.[1] Current atmospheric concentrations of the most powerful GHG (carbon dioxide and methane) are already at the highest levels registered in the last 450,000 years. Due to the large time scale of the climatic process and to feedback mechanisms between the climate subsystems, global warming will continue for centuries even if GHG concentrations stabilize at current levels.

There is surging evidence that GHG emissions accumulated from the beginnings of industrial evolution have already produced long-term changes in Earth's climate, like rising mean temperatures in the Arctic with shrinking ice surface in the Summer, glacier melting, changes in long term patterns of precipitation and droughts, generalized changes in extreme temperatures, and increase in cyclonic activity (see IPCC, *Fourth Assessment Report*, WGI, 2007). Even though there is no scientific consensus, many observers argue that even an additional 2°C increase in global temperature (with respect to the 2000 level) is enough to trigger irreversible, probably catastrophic, changes in the fundamental physical conditions of the biosphere.[2]

According to a large number of climate models, the path to avoid dangerous climate change above a 2°C increase along the century is to stabilize GHG emissions, in terms of CO_2 equivalent, at the range of 450-500 ppm. To attain this, human GHG emissions must be

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[1] To put it in perspective, mean global temperature differences between an Ice Ages and interglacial periods locate around 5°C.

[2] See on this point Lenton et al (2008). The European Union definition of dangerous global surface temperature increase is 2°C with respect to the year 2000. Hansen et al. (2008) argue that a 1°C increase above 2000 levels would already constitute dangerous human interference with climate.

reduced between 60% and 80% by 2050, with respect to 2000 emissions (IPCC, Fourth Assessment Report, WGIII, 2007). In order to reach a stabilization plateau of 450-500 ppm of CO_2 eq. by 2050, CO_2 emissions must peak between 2000 and 2015.[3] Weaker reductions will imply GHG stabilization at higher levels and higher temperature increase. In Table 1 we summarize the possible stabilization scenarios and their impact on climate change.

Considering current emission trends, it seems highly unlikely that the world will make it on time to reach the “safe” mitigation scenario (keeping concentration levels at 450-500 ppm). This is even more worrying when considering that the physical processes and the economic choices relevant for climate change have such long-lasting effects that they should be treated as irreversible (Schmalensee, 1998). Delaying mitigation efforts would demand faster rates of mitigation in the future. Therefore, mitigation efforts would have to proceed considerably faster than projected in that scenario.

While the required effort looks overwhelming, several studies and assessments have concluded that available technical options could provide results that actually very close to those objectives (IPCC, 2007). Moreover, recent cost-benefit analysis supports the proposition that mitigation is not only less costly than facing the costs of climate change, but that it can actually produce incentives to economic growth.[4] But such the widespread

[3] In contrast, the Kyoto Protocol scheduled a 5% reduction by 2012 with respect to 1990 levels, for the group of industrialized countries.

[4] The most famous study of this kind is the Stern Report, which found that while costs of stabilization would range between 1% and 3% of GDP, costs of inaction would reach between 6 and 20%. Cost-benefit analysis for environmental regulation has been subjected to strong criticism and remains highly controversial. On the theoretical side, Ackerman and Heinzerling (2002) identify four fundamental flaws of cost-benefit analysis: 1) Standard economic approaches to valuation are inaccurate and most of the time implausible; 2) the use of discounting improperly trivializes future harms and the irreversibility of certain environmental problems; 3) relying on aggregate, monetized benefits excludes the dimension of justice; 4) the value-laden and complex cost-benefit process is neither objective nor transparent. On the empirical side, it has been widely acknowledge that small differences in underlying modeling can yield totally different cost assessments. For example, in 2005 the Competitive Enterprise Institute stated that complying with the Kyoto Protocol would

process of technology adoption required for the transition to a lower-carbon carbon economy depends on a throughout reorganization of international production and consumption patterns, as well on a sound international framework for regulating emissions.

Regulating global rights

Emission cuts established in the Kyoto Protocol were based on a simple principle: rich countries should take action while poor ones skip reductions for the time being. Although physically insufficient and weakly enforceable, the Protocol constituted a successful first step to unlock the initial coordination trap produced by a situation of ubiquitous responsibility and global impact, where no country would take action before others did. Crucial for the negotiation was the recognition of two basic principles at United Nations Framework Convention for Climate Change (UNFCCC). The first is the precautionary principle, which justified action before having full and complete knowledge about the physics of climate change. The second is *common but differentiated* responsibility, according to the evidence of differential per capita emissions and income levels. Based on these same principles, this framework must be updated and retooled to secure a mitigation schedule that matches current knowledge about non-dangerous stabilization levels.

International asymmetries in terms of per capita income, per capita emissions, and per capita energy-use remain strongly significant. Developing countries are responsible of only 23% of global cumulative emissions since 1750 (Raupach, et al., 2007). However, recent trends show the high sensitivity of emissions to small changes in the pattern of world income levels, which has pulverized earlier "de-carbonization" trends (Grübler, 1994).

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cost USD 300 billion per year to the US, 20% of GDP over 10 years. At the same time, for Amory Lovins reduction in carbon emissions would save USD 300 billion (quoted in Lohman, 2007, p. 115, not 192).

Despite meager gains in per capita income levels and of growing international divergence, developing countries account now for a considerable share of the increase in emissions (70% of emissions' growth in 2004). Increasing energy demand and growing per capita income will increase the pressure on the Earth's carbon cycling capacity just when curbing emissions will be most demanded.

The surge of GHG emissions in large developing economies like China and India reflects the extent to which declining energy intensities have been offset by increasing carbon intensities and rapid economic growth. Such a pattern of rising carbon intensities has been attributed the acceleration of coal-based electricity generation and a rapidly growing transport sector fuelled by oil (Rogner, et al., 2007). However, in order to attain stabilization levels in GHG concentration between 450-500 ppm CO_2-eq developing countries will anyway need to curb emissions shortly after developed countries do, in the next couple of decades (see Baer, Athanasiou and Kharta, 2007).

While they are relatively less responsible of cumulative emissions, developing countries will suffer earlier and more strongly the impacts of climate change. All countries will need to adapt, but poor countries will have to do that earlier and with weaker adaptation capabilities and resources. While impacts on islands and coastal populations has been most publicized, objective danger gravitates on water resources, food security and human health, as well as on the sustainability of terrestrial and coastal ecosystems (UNFCCC, 2007). For example, the UNU Institute for Environment and Human Security predicts that the number of "environmental refugees" could grow from 20 million people in 2005 to 50 in 2010 and up to 150 million in 2050 (Myers, 2005). The UNFCCC estimated that investment flows required for adaptation are sum up billions of dollars per year, several decades from now, and could reach more than USD 100 billion per year (UNFCCC, 2007). In order to reduce adaptation costs, mitigation must proceed fast.

A workable definition of common but differentiated responsibility cannot ignore these facts. The reluctant position to initiate emission reductions, held by most developing countries with the legitimate argument of having a right to development, is weakened when considering that a) global inaction will defeat any isolated development effort; b) developed countries, especially the U.S., will not commit to stronger mitigation if major developing countries do not follow suit. It is therefore in the highest interest of developing countries to foster mitigation solutions both in developed countries and in their own.

There exist two important frameworks for updating the Kyoto Protocol. First, the Contraction and Convergence Framework (Meyer, 1997) establishes for each country a specific mitigation schedule that satisfies two conditions: securing global stabilization of GHG at 450 ppm by 2100 and gradual convergence to equal per capita emission levels. Complementary, the Greenhouse Development Rights Framework integrates the notion of global *responsibility* with that of national *capacity* (Baer, Athanasiou and Kharta, 2007). The first concept calculates the responsibility of each country on its share in global annual emissions; the second exempts all individuals living under a poverty line from sharing the burden of financing climate action. By including intra-country income differentials, this second approach addresses the fact that high-income individuals in poor countries have indeed a capability of contributing to mitigation. An integrated framework based on these two approaches could narrow down the most visible resistances to set up a renewed international agreement on climate change.

The reluctance of the United States to commit to quantitative emissions reductions remains the strongest obstacle to effective climate action. The U.S. exercise of the privileges of hegemony seems to have actually stretched out in the last decade. But it should not be forgotten that legitimacy is a condition of sustained hegemony. Awareness on this fact within the commanding structures in the U.S., at a moment when the international financial crisis strengthens the need to reorganize the world economic order, could open a window for articulated, effective international pressure to bring the U.S. into an improved climate deal.

Technology and the fossil-fuel regime

Global GHG mitigation implies, broadly speaking, increasing energy efficiency and reducing the carbon content of energy, as well as reducing deforestation and land use change. Even though energy use concentrates more than 50% of the GHG emissions sources, the latter are rather ubiquitous throughout the economy. In fact, mitigation at national levels implies to restructure multiple technological systems and practices, involving hundreds of different technologies.[5]. However, overall mitigation does show important generic aspects.

According to the last report of the Intergovernmental Panel on Climate Change (IPCC), during the period 1970 to 2004 global emissions have risen as the combined effect of global income growth (77%) and global population growth (69%), which have surpassed the general decrease in energy intensity of GDP (-33%) and the almost null reduction in carbon

[5] A popular image is to represent carbon reductions in time coming from different sectors as "wedges." (see Socolow and Pacala, 2006). While a useful start, these views are based on a static approach that cannot offer support for coherent mitigation strategies.

intensity of energy (-2%).[6] In other words, "declining carbon and energy intensities have been unable to offset income effects and population growth" at a global scale, rising consequently carbon emissions (Rogner et al., 2007, p. 107). As can be appreciated from Graph 2, energy efficiency improvements have been persistent along the last 30 years, while changes in the fuel mix (and the carbon content of energy) are weak. These trends reflect the slow incremental improvement of a technological regime based on fossil energy, and its rigidity to change its fundamental principles. The different uses of energy have developed increasingly efficient solutions without changing their basic design, which determines carbon emissions.[7]

Many renewable energy sources are available now at costs that are not radically different from fossil fuels. However, there exist strong rigidities to phase-out the fossil-energy pattern. First, for a society that is headed to an ever-growing consumption of energy, fossil fuels have technical advantages over their substitutes: a very high energy density and a very high rate of energy return over energy investment; high flexibility and large variety of uses; ease of storage that allows a constant intensity of energy flows. These features allow the acceleration of production processes, their independence from other biological and social processes, and ultimately a "compression of time and space" that matches tightly the logic of capitalist accumulation (Altvater, 2006). Second, fossil fuels are abundant: reserves of conventional fossil fuels are large enough to secure a constant supply at current use levels over the next century (Cavaney, 2006; IPCC, 2007); non-conventional sources easily

[6] This calculus does not consider emissions derived from de-forestation and land-use change.
[7] Energy transitions are driven by succession of technologies. Initiating from a very small scale of use, a new technical base gradually improves in efficiency and variety of applications, until it eventually replace the previous energy base. The emergence of a fossil-fueled economy is the result of a sequence of rising structures based on a dominant fuel (wood, coal, oil, and currently natural gas), along a path of increasing energy use during the last 250 years. These transitions depict changes in the relative weight of energy sources, rather than full replacement (the current transition from oil to gas includes as well a rebound in the use of coal).

duplicate those reserves. Third, there is a huge mass of sunken investments in the form physical and technical infrastructures specialized in the production, distribution, storage, transport, and consumption of fossil fuels, as well as in other less tangible long-life investments that provide cheap or inexpensive services to fossil-fuel systems. Sunken costs, the existence of specialized technological infrastructure, and inter-locked supply and demand are all factors that generate increasing returns to adoption of fossil technologies, locking-in future technological choices to fossil energy sources. These rigidities tend to reinforce each other in such a way that marginal changes in incentives will not induce technical change in the basic principles of technology, even if alternatives are available.

A widespread energy transition demands higher-level innovation to build up entirely new energy systems. This process will take time and will not occur spontaneously from market processes. It will involve intensive exchange of intangible goods and other services difficult to value and appropriate, decision-making under strong uncertainty, choice against large sunken costs, and other advantages from learning and cumulativeness, all factors that make the case for strong coordination and planning. However, most international efforts to deal with mitigation and adaptation to climate change are running precisely into the opposite direction.

Carbon Markets: drawbacks of privatization

The current institutional framework, delineated by the Kyoto Protocol, establishes three financial instruments aimed at facilitating emission cuts: Carbon Emission Trading, Joint Implementation the Clean Development Mechanisms (see for example Schmalensee, 1998). The goal of these instruments, known as Flexible Mechanisms, is to reduce mitigation cost. Carbon Emission Trading (CET) constitutes the backbone of Flexible Mechanisms, and it absorbs most of organizational and financial resources devoted to climate change institutions.

CET or “Cap and Trade” schemes are supposed to influence the normal procedures of valuation and allocation of economic activity through a system of trading allowances. Its theoretical foundation is a theorem by R. Coase’s that states that if property rights exist, private arrangements would guarantee optimal allocation of resources and optimize pollution, independently of the distribution of rights (Ellerman et al., 2003). Practical application of Coase’s theorem is due to J.H. Dales who first advanced to idea of controlling pollution via emission markets. Emission Trading was first applied by the U.S. Environmental Protection Agency (EPA) to control emissions sulphur-dioxide in power facilities, in 1976. Three the Agency set emission targets for polluting facilities and in 1990 the Clean Air act Amendments established the specificities of the trading program (ibid.).

“Cap and Trade” schemes function in the following way. The government establishes a cap or maximum level of pollution for a certain period, and distributes accordingly a given number of allowances or permits to selected polluters. Emissions are to be monitored and those who emit beyond their allowance will be fined, in order to keep overall emissions to the level of the cap. Allegedly, trading allows the convergence to the cap to occur in a cost-effective way. On the supply side, the promise to obtain a flow of cash by selling unused allowances would become an incentive to reduce emissions. On the demand side, it is argued, those who face expensive emission reductions would save by buying available allowances from those who were able to carry on large emission cuts at a low cost. These schemes are promoted as “win-win” solutions to pollution control, since firms with high mitigation costs can buy permits at a lower cost, while firms with low mitigation costs earn money by reducing emissions and selling permits. The government controls scarcity according to strategic goals by setting the cap, while the market is supposed to allocate available resources in the most economical way to fit under the cap.

Despite their alleged advantages, CET schemes have strong handicaps that must be seriously considered before assigning them an hegemonic role in mitigation policy.

1. On the theoretical side, there are serious contentions that they are based on flawed theory. Specifically, Coase's theorem has been disputed as a consistent mechanism of efficient allocation. According to Nadal (2008), the underlying bargaining process does not necessarily produce the outcome of social efficiency in the sense of Pareto, even in the simple case of a bilateral monopoly. On one hand, the results of bargaining may not be independent of the distribution of rights; on the other, negotiations may reach mutually beneficial positions for the incumbents that fall outside the region of socially optimal contracts. The alleged efficiency of these kind of markets cannot is not supported by a consisted theory.

2. Carbon markets do not strictly "internalize" the cost of GHG emissions. They are argued to save the effort and difficulties of calculating emission costs, by relying rather on the exchange value of emissions rights set by the market. The environmental "cost" on the political decision that sets the cap. However, the latter is not the outcome of a market process, not even the outcome of a democratic process, but rather the result of a *real-politik* process bargaining and lobbying between governmental agencies, parliaments, and involved corporations. In this sense the CET scheme, "rather than providing an antidote to the problems of complex decision-making that plague traditional regulation, provides a layer of additional complications and occasions for dispute." (Driesen, 1998).

3. Allowances are 'assets…owned by the company concerned… and as such represent a significant and immediate creation of value to companies' (Lohman, p. 77). How are these assets created from nothing? Basically, allowances or quotas worth something because they have exchange value: the can be traded for other assets. "The new carbon commodity is ghostly only in the sense that it's up to governments and governments alone to decide – on whatever grounds they choose, scientific or not – how scarce it is, and how much can be distributed, bought, sold and used." (Ibid, p. 79). The creation of carbon markets, and the underlying distribution of property rights, is then highly dependant on political decisions and power leveraging. Interest groups will continuously push for changes in allocation driven by the enormous rents at stake (Cramton and Kerr, 2002, p. 343). By relying on the distribution of pseudo-property rights (assets which represent a stream of income), emissions trading schemes introduce a distributional aspect that is essentially unequal and unjust.

4. The governments' dilemma is that they cannot make pollution trading programs flexible and credible at the same time. The goal o reducing emissions "pulls trading systems one way – toward giving regulators a free hand to modify allowances." But at the same time "Governments' need to reassure traders that they will not be expropriated unfairly pulls another way – towards protecting allowances against government modification and making them as much like full title as possible" (Lohman, p. 82). At the same time, this makes the political process of lowering the cap (or introducing a "ratchet") more difficult as the mechanism creates strong vested interests. The excess supply of allowances that plagued the European Carbon Market and eventually caused carbon prices to plummet exemplifies the type of difficulties in balancing political viability of the mechanisms with effectiveness.

5. Another important handicap of CET schemes is that they can in principle produce fictional emissions reductions through very complex procedures and rules that result difficult to evaluate and monitor. Unlike real markets, sellers and buyers find incentives to inflate reductions, making it very difficult to assess calculus of baseline, credits, and additionality.

6. CET mechanisms will tend to reduce mitigation efforts: if mitigation rate increases, carbon price will fall, stalling further mitigation.[8] If there are many cost-effective carbon saving projects in line but carbon credit demand is stalled (due to initial excess supply of allowances, or in the case of reduced capacity utilization), the market solution creates an incentive to hold back mitigation investments. Society losses twice, by missing cost-effective investments, as well as the derived learning gains and scale economies. Particularly in the case of poor countries, extensive dependence on CET flows from the Clean Development Mechanism[9] would rather damp than foster an articulated response to low-carbon transition, crowding-out local investment from "cheapest" mitigation efforts and probably even sucking-in local resources in order to "facilitate" corporate investment oriented to maximize private profiting.

7. CET schemes, as markets of other pollutants are extremely volatile due to the short-term rigidity of supply and demand. This aspect questions seriously the ability and accuracy to produce effective signals for long-term choices as those involved in mitigation investment. Futures and other speculative instruments are equally questionable.

[8] It is in this sense that emission trading schemes provide "equal measure of under-compliance and over-compliance incentives, inducing less innovation than a performance-based standard to which everyone has incentive to comply" (Taylor, et al, 2005. p. 372).

[9] According to art. 12 of the Kyoto Protocol, developed countries are entitled to finance mitigation projects in developing countries and receive in exchange a Certificate of Emissions Reduction (CER), a form of carbon credit. This instrument is called the Clean Development Mechanism (CDM).

8. The short-term cost-benefit selection criteria implicit in CET schemes will most likely bias technology choices towards lowest-cost options and incremental change, without hierarchically distinguishing among innovations. This aspect is crucial and should be explored in detail. Carbon trading schemes are based on premises about the allocation process of *existing* resources, ignoring that mitigation is innovation: it is all about creating *new* resources. Mitigation efforts are fundamentally technology choices and in this sense they are "structural" decisions: they change the range of available choices in future decisions. It is well accepted in the literature on technical change that feedback from past decisions, as well as other sources of local increasing returns (sunken costs, learning economies, and technical interrelatedness), introduce self-reinforcing mechanisms in the trajectory of technological change (Arthur, 1989). Under these circumstances, the relative superiority among choices is not independent of the sequence in which choices are made. Once a technology is chosen among options, knowledge about it will improve, specific infrastructure will be deployed, and fixed resources will be installed, increasing the attractiveness for choosing this technology in the future. There are many consequences relevant for theory and policy making, but one of the most relevant here is that markets can select suboptimal technologies, and "crystallizing" resources for a very long time.[10] Technological change is an open process, subjected to the effect of cumulative causation that can potentially exhibit multiple equilibria and lock-in.

By favoring incremental change on the permits supply side and prolonging high-carbon emissions on the permits demand side, these schemes will reinforce established processes and technologies. This feature is relevant when considering the above argument about

[10] See Arthur (1988, 1994) for theoretical demonstrations, and David (1985) and Cowan (1991) for empirical cases.

current carbon-intensive technologies being locked-in or "entrenched." With technologies enjoying increasing returns to adoption, marginal improvements only dig deeper into the dominant regime's advantages. By privileging private benefits and ignoring social returns CET will sacrifice dynamic for static efficiency, becoming an ineffective tool for systemic structural change.

9. There is another aspect of dynamic efficiency closely related to the previous one. As argued, without higher-level coordination CET schemes are more likely to select earlier the lowest-cost mitigation projects, not those with a stronger mitigation potential from a system's point of view. But it is a well known fact that systems' optimization cannot be attained by optimizing components in isolation. Especially in large technological systems, like those of energy supply-chains, radical innovation involves institutional coordination involving several types of institutions (firms, governments, regulatory agencies, technical standards, property rights, etc.; see Hughes, 1983, for a classical reference). It is not clear whether CETs will obstacle or facilitate this kind of coordination, but they will definitely not provide for it.

10. Finally, a dominant focus on carbon trading schemes fails at addressing the broader and most important issue of technological transfer and public investment in research, demonstration, deployment, and development. The underlying assumption is that trading incentives in combination with strong enforcement of intellectual property rights would generate the necessary incentives to invest in R&D and technology transfer. This argument does not consider the obvious fact that IPRs are actually intended to deter technological imitation and condition technology transfer to direct investment or royalty payments. Especially in the context of developing countries, IPRs do not facilitate, and in practice

they tend to block, the accumulation of technical capabilities and knowledge for assessing, imitating, improving, and eventually mastering technologies.

CDM's and Carbon Credit mechanisms present additional problems. There are risks of emerging conflict of interests on the part of private consultants assessing Emission Reduction Projects. But the basic problem is that measuring emissions is completely different from measuring carbon credits. First, to have access to the CDM, a mitigation project must demonstrate non-additionality, that is, that the project would have been impossible without carbon finance. But this is actually highly problematic, due to the 'impossibility of measuring or even defining savings that are additional to those that would have occurred in the absence of emissions credit" (Grubb, 1999, p. 138). Second, carbon credits are calculated as saving from "business as usual" baseline, chosen among many plausible options of future. But this choice is basically a political decision, rather than an economic or technical prediction. "'Emissions reductions' for many projects can be expected to differ by hundreds of percent given only small changes in initial assumptions" (Lazarus, 2003). Lack of verifiability opens the way for "creative accounting" and artificial creation of carbon credits. Third, CDMs generates a perverse incentive to delay mitigation policies in developing countries in order to enlarge the baseline from which emissions cuts will be calculated in the future. Finally, due to the relatively small amount of resources made available by the CDM mechanism, strong competition may result deleterious with respect to local benefits of investment, eventually triggering a "race to the bottom" in standards similar to that resulting from competition on other types of international investment.

These handicaps do not necessarily lead to discard completely market mechanisms as instruments to promote mitigation. But they cannot be expected to function as self-regulating, efficient, non-distortive mechanisms, or as the backbone of every mitigation strategy. Without the proper institutional setting, a hands-off approach to market solutions will generate distributional distortions, slow innovation, and inefficient allocation of resources. In particular, developing countries are at risk of loosing strategic control and decision power over their technological base when relying passively on CET for defining a mitigation strategy. Below we argue that instead of relying solely or even mainly on market mechanisms, mitigation policies at the national level would be more effective and efficient if they take a hands-on, industrial and technology policy orientation.

Technology: innovation and systemic change

Mitigation strategies consistent with the speed and degree of structural change demanded to reach precautionary GHG stabilization levels must consider technical change in a more realistic way.

One can summarize a realistic approach to technological change by highlighting three main features. First, technological development is a profit-driven, cumulative learning process, induced by the promise of obtaining monopolistic rents in real-competitive markets. Second, technology is not a public good similar to information: it is made up of costly packages of physical and intellectual resources, including skills and knowledge that can only be acquired through experience. Third: technological decisions are embedded in their application environment, which is crucial to understand the dynamics of technological change. These features of technological change have important implications for mitigation policies:

1. Technology diffusion is not automatic, but dependent on a multifactor selection process determining adoption thresholds (David, 1969). Such thresholds can be highly unresponsive to changes in relative prices, making market selection mechanisms impotent to attain objective mitigation goals. Barriers to adoption would tend to be country, sector, and even technology specific.

2. Diffusion and technology choice are subjected to (transient) local increasing returns from learning. Feedback between investment and learning by doing can create waves of investment biased to certain technological configurations. Technologies that benefit from investment flows are more explored and eventually become cheaper; in turn, profit rates of those technologies increases, making subsequent investments more attractive. From the perspective of latent new GHG mitigation technologies, the argument works the other way around. As long as investment is kept off from alternative technologies, the latter will remain unexplored and expensive. Tapping the development potential of technological alternatives by redirecting investment flows into niches of use and explorative fields becomes crucial for increasing diversity and breaking the inertia of carbon-intensive technologies "crystallized" in the capital stock.

3. Technology is embedded in technology regimes, which interconnect firms' production and technology flows, innovations rules, and institutions. These organs define, focus and solve technical problems, and depend to a great extent on the processing, adaptation, and socialization of technical knowledge. Their degree of development will strongly vary across countries. The industry's response to incentives is processed and determined by the workings of these regimes. In the case of GHG emissions mitigation, relevant technologies exhibit immense variety and specificities, some sectors may only need shifting standards up

(car motors, housing energy), others would require changing conditions for technology adoption, control, and diffusion. Market incentives are useless without intervention into the surrounding systems that are carriers of change. This, together with the argument of un-tradability of technical skills and knowledge, implies that large-scale technological development depends strongly on the development of a minimum base of learning infrastructure and investment in local capabilities.

When technology adoption takes place under conditions of increasing returns (due to learning by doing, technical interrelatedness, etc.) a coordinated process that values social gains is more likely to avoid choosing an inferior technology, in comparison to a market process (Cowan, 1991). However, even a coordinated process cannot totally avoid lock-ins. The policy lesson of technology choice under increasing returns is that governments and other higher-level institutions must promote technological variety even when it increases short-term costs of technological development under the rationale that social gains will be higher in the longer term.

Due to the long-term nature of fixed assets in the energy sector, diffusion of mitigation technologies in energy generating, energy-intensive, and other capital intensive industries will be highly dependent on macro-economic factors determining capital turnover rates, like rates of interest, demand growth rates, and the wage rate. Mitigation will require sound macroeconomic environments.

Radical innovations like new energy and transport systems require specific incentives to develop. Renewable energy is geographically specific, intermittent, and strongly dependent on interconnection systems, as well as on public infrastructure. There are many models to develop renewable energies, but not all of them provide the same local benefits.

Developing countries in particular should aim at maximum involvement in technology transfer by constructing and expanding local innovation systems and appropriate technology. Solid local infrastructures improve adaptation, faster advance and learning, and improved economic and social benefits like energy security and independence, value added creation, and social control of technology. Mitigation and development are not alternative paths, but under the proper strategy they can become powerful self-reinforcing dynamics.

Investment in public infrastructure, research and development facilities, and education is crucial to construct effective systems for learning, socializing, an improving technical knowledge and technology selection criteria.

Discussion: new institutions for structural change

Climate change strategies oriented to fulfill the kind of structural change necessary to bend economic systems towards low-carbon profiles demand policy space to implement industrial, technological, and energy policies based on well-defined technical standards. As shown by historical experience on successful industrialization, technology-oriented development works better when private investment is subjected to specific mechanisms that balance support with disciplinary control (see Amsden, 2001; Chang, 2002). However, global institutions have evolved in the last three decades into a direction that has systematically reduced national policy space (Gallagher, 2005).

A global mitigation strategy requires, first, a new institutional framework that guarantees a credible, fair, and effective mechanism for regulating the international use of the atmosphere without disrupting the carbon cycle, following the precautionary principle stated in the Kyoto Protocol. This mechanism should consider common but differentiated responsibility, as well as differentiated capacity. A credible consensus must include democratic procedures of agreement, as well as effective monitoring and enforcement.

Second, global mitigation demands a broader degree of policy space at the national level to instrument flexible, adaptive mechanisms to foster innovation. Transition to low-carbon economies requires to un-lock entrenched technical systems and re-direct structural change towards a lower use of energy and materials. Market mechanisms are unable to facilitate this transition without strong guidance and complementary instruments. National strategies must therefore take a technology-oriented approach to mitigation and design sector specific policy package taking advantage of a broader toolbox of instruments: a) carbon taxes; b) technology standards; c) subsidies to adoption of renewable energy, local technological learning, and traditional agricultural systems. Additionally policy packages should include investment funds labeled at the sub-national level in order to support economic and environmental adaptation of less-privileged communities. These policies should be designed and adapted following national interests and local characteristics of the productive structure. The reconstruction of state and social capacities to re-orient coordinately economic development is imperative. This task faces formidable institutional barriers erected in the last two decades of free trade and investment agreements.

Systemic change demanded by GHG mitigation cannot be reduced to technical efficiency and changes in fuel mixes. It is imperative to redirect development goals from ever-increasing material wealth towards the satisfaction of radical necessities and a sustained reduction of energy and material use.

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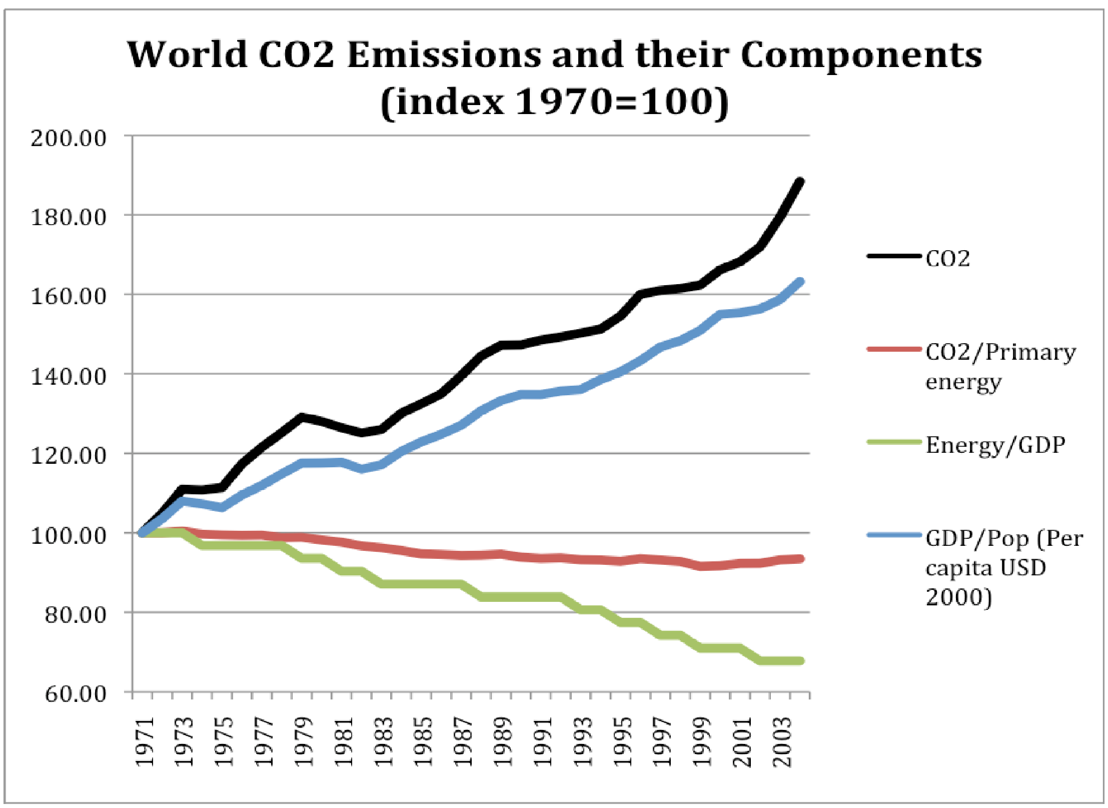
Table 1

Greenhouse-gases Stabilization Scenarios (117 scenarios)					
Category	CO_2 concentration (ppm)	CO_2-eq concentration	Temperature increase (base 2000)	Year of CO_2 emission peak	Change in emissions by 2050 (% 2000)
I	350-400	445-490	20-2.4	2000-2015	-85 to -50
II	400-440	490-535	2.4-2.8	2000-2020	-60 to -30
III	440-485	535-590	2.8-3.2	2010-2030	-30 to +5
IV	485-570	590-710	3.2-4.0	2020-2060	+10 to +60
V	570-660	710-855	4.0-4.9	2050-2080	+25 to +35
VI	660-790	855-1130	4.9-6.1	2060-2090	+90 to +140
Source: AR4 WGIII, IPCC, 2007.					

Table 2



Sources: International Energy Agency, International Monetary Fund.