Limitations and biases of conventional analysis of climate change. Towards an analysis coherent with sustainable development

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Abstract

This paper shows the numerous problems of conventional economic analysis in the evaluation of climate change mitigation policies. The article points out the many limitations, omissions, and the arbitrariness that have characterized most evaluation models applied up until now. These shortcomings, in an almost overwhelming way, have biased the result towards the recommendation of a lower aggressiveness of emission mitigation policies. Consequently, this paper questions whether these results provide an appropriate answer to the problem. Finally, various points that an analysis coherent with sustainable development should take into account are presented.

Key words: climate change, conventional analysis limitations, emissions control, evaluation of policies, sustainable development

1. Introduction

The warming of the Earth has generated an environmental concern without precedent. At the same time, it has become obvious that the conventional economic analysis as well as the management and evaluation methods that it prescribes are not able to give an appropriate answer.

One particularity of climate change is that the consequences for each country do not depend on its individual contribution but rather on the global deterioration. Another characteristic is that its effects are long lasting, if not irreversible. Lastly, the impacts of the alterations are hard to determine since the processes are so complex. Because of these characteristics, together with the free access to an environment shared by all present and future individuals, the necessary incentives for an appropriate administration are not given.[1] Therefore, we are dealing with an externality problem of unknown magnitude, which affects a public good at global scale and at both at intra- and intergenerational levels. In this context, the typical prescriptions to the externalities problem do not represent a solution. The public concern aroused by the greenhouse effect is reflected in the number of international conferences organized to discuss it. The most visible result has been the commitment to reduce emissions set down by the Kyoto Protocol in 1997 and the agreement to make it operative in Bonn 2001. However, in spite of the notable softening of the terms agreed to in Kyoto, it has not been able to include the major countries responsible for the problem. This concern is more than justified if one takes into account the greater climatic instability and the natural disasters experienced in the last decade that have been related to climate change, such as hurricane Mitch in 1998 and the floods of Venezuela in 1999. Unfortunately, conventional economic analysis has failed to provide solutions for this concern, and it has been used rather to legitimatize and give a "scientific" justification to the no-regulation policy and the free performance of the energy sector.

The paper is organized as follows: Section 2 briefly explains the uncertainties of the greenhouse effect, its consequences on climate, and the impacts of climate change. Section 3 studies

[1] Usually this problem is identified with "the tragedy of the commons" stated by Hardin (1968). This is not correct since common management of public goods works appropriately in many cases. The problem is rather the "free access" one, where there is not any management limiting the use of the resources (Pearce, 1999, p. 490).

the problems of conventional economic analysis and Section 4 studies the biases, omissions, and the arbitrariness that have been introduced in the study of policies to mitigating climate change. Section 5 highlights some points to be considered for an analysis coherent with sustainable development. Section 6 presents the conclusions.

2. Greenhouse effect and climate change

Global warming and the resulting climate change takes place due to what has been termed “the greenhouse effect”. This is a natural phenomenon, caused by a series of gases present in the atmosphere and it is responsible for the temperatures that make the Earth inhabitable. The problem arises because human activity has accelerated the accumulation of these gases and, as a consequence, the warming process has also been accelerated.[2]

2.1. Uncertainties associated to climate change

Under certain conditions (risks exogenously determined, and certainty about the different possible results and their respective probabilities) conventional methods can lead to an efficient allocation of resources in the presence of risk. These conditions are not given in the case of climate change, where the risks are poorly understood and depend on human performance. There is uncertainty and ignorance about basic questions. First, there is the difficulty of measuring emissions, and even worse, of making predictions about future concentrations. Second, there are many interactions that complicate the study of the relation between emissions concentration and warming.[3] Third, even assuming a certain level of warming, there is a great uncertainty about the climatic impact on the different regions of the world. Fourth, there is the difficulty to identify and estimate the magnitude of the impacts that climate change might cause on the environment and on human well-

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[2] According to the IPCC (2001a) between 1750 and 2000 CO_2 emissions have contributed 60%, CH_4 19.8%, CFCs 14%, and N_2O 6.2%, measured in terms of radiative forcing.

[3] Some greenhouse gases produce chemical interactions (causing problems such as the ozone layer depletion or acid rain) and their final effect on global warming is much more difficult to determine than in the case of CO_2.

being. Lastly, the uncertainty persists when considering what sacrifice (in monetary terms) a stricter control of emissions would imply. In each one of these stages the collaboration of specialists of different fields becomes necessary. In climate change, more than in any other problem, it becomes clear that the management of a sustainable development is an interdisciplinary task.

2.2. Global warming and climate change

According to the Intergovernmental Panel on Climate Change (IPCC, 2001a) the average temperature of the terrestrial surface has increased around 0.6ºC since 1861. It is estimated that the increase in the last 10000 years has been 1ºC, the rate of warming being constant until the last decades of the XX century in which it has increased to 0.15ºC per decade. The IPCC estimates that the average temperature could increase between 1.4 and 5.8ºC between 1990 and the end of XXI century. This is a warming without precedent in human history, causing a rise in sea level between 0.09 and 0.88 meters.

However, the real problem of global warming is not the average increase in temperature, but the associated climatic anomalies and changes that might occur. The result of global warming can be more heat or more cold, more rains or more droughts, depending on the region and, in general, more climatic instability with an increase in the frequency of natural disasters such as hurricanes, droughts or floods. The relationship between average warming and climate change is a complex one. The increase in average Earth surface temperature might be a useful indicator of the severity of the problem, since the greater the warming the more the climate alterations. However, nothing indicates that this relationship is a linear one.

2.3. Climate change impacts

Agriculture losses, losses in biodiversity and forests, sea level rise, illnesses, energy costs, migration costs, natural disasters, losses in recreational activities, and water supply problems are some of the foreseeable impacts. Several models of integrated assessment have been made in order to incorporate the interrelations between climate and economy (a review can be found in Rotmans et al., 1998). These models present estimations, in monetary terms, of the impacts of global climate change and emission reduction policies. On the whole, it is calculated that global GDP would change little with small temperature increases while greater temperature increases would boost the net losses (IPCC, 2001b). The impacts would be much greater in poor countries, due partly to their lower capacity to adapt and their bigger vulnerability; in some cases, the local impact could be catastrophic. However, the impact difference in different areas brings about serious problems in the search for solutions because it accentuates the free-rider incentives caused by the "public good" nature of emissions control policy.

According to the IPCC there is the possibility of extreme impacts, like changes in ocean currents, a considerable melting of polar ice-caps, and an accelerated warming due to the release of carbon and methane pockets or to carbon cycle feedbacks in the terrestrial biosphere, among others. Should they occur, their effects would be of great magnitude and irreversible in the long term. Although it is unknown, we can speculate that the probability of these phenomena depends on the rate, magnitude, and duration of climate change (IPCC, 2001b). However, this probability is simply ignored in most models' calculations.

According to most calculations, one would need to sacrifice around 2% of the global annual GDP to make a significant difference in the control of emissions. As Schelling (1992, p. 8) affirms, it only "postpones the GDP of 2050 to 2051". Nevertheless, in general, current models suggest that it is not profitable to take action for mitigating climate change, or that the action should be very limited (e.g. Manne and Richels, 1992, 1999; Peck and Teisberg, 1992, 1994, 1999; Nordhaus, 1993, 1994; Manne, et al., 1995; Nordhaus and Yang, 1996; Chakravorty et al., 1997; Nordhaus and Boyer, 1999; Hamaide and Boland, 2000). However, these models have many limitations, biases, and omissions that seriously question the validity of their solutions.

3. Problems of conventional analysis applied to climate change

Many of the models that have been used are based on traditional economic instruments such as cost-benefit analysis (e.g. Nordhaus et al., various years; Peck and Teisberg, 1992; Manne et al., 1995). On the other hand, diverse models have also been created to search for cost-effective paths to reduce emissions and achieve specific emissions or atmospheric concentrations goals. These models, in spite of not being as pretentious as global cost-benefit analyses, maintain a good part of the limitations of conventional analysis and most of them also incorporate strong biases in assumptions that are critical for their results, which limits their capacity to give appropriate answers.

3.1. The discounting of climate change impacts

Part of the controversy about the models applied to climate change has focused on the choice of the discount rate.[4] The social discount rate (s) in these models used to be expressed with the Ramsey formula:

$$s = \rho + \eta g$$

where ρ is the pure time preference rate, η is the elasticity of marginal utility (absolute value) and g is the growth rate of per capita consumption. That is to say, discounting is applied because of impatience and the belief that in the future there would be more wealth.

Conventional analysis applies the time discount of present society to discount all costs and benefits that will occur in the future, as if all future impacts occurred to present individuals. In general, the models consider all humankind as if it were an immortal agent. It seems clear that the unreal assumptions of conventional discounting cannot lead to an allocation consistent with individuals' preferences. The consumption of future individuals is discounted with a rate that shows the impatience in the own consumption of present society, while the logical procedure would be to consider the preferences regarding the well-being of the future generations suffering climate change impacts. The issue is how do we value this well-being and not what do we want to save in order to increase our future consumption. An intergenerational weighting appropriately showing these preferences should be applied (Padilla, 2002). In addition, if a discount rate above the rate of economic growth is used, then the current cost of a significant control of emissions expressed in future value could be larger than the whole future GDP (Rabl, 1996). Deciding not to do anything from the beginning would be cheaper and more honest that using this device.

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[4] Cline (1992), Nordhaus (1994), and Fankhauser (1994) agree about the importance of this choice for the prescribed mitigation level of greenhouse gases.

The argument of the decreasing marginal utility of consumption is also controversial. To apply a high discount rate because of an assumed future prosperity could lead to compromising this very prosperity because of undervaluing the impacts of future climate change. Moreover, many of the models applied to climate change extrapolate future rates of economic growth from past behavior, without considering the negative impacts that this growth has caused on the environment. If discounting is applied to future individuals because of the belief they will be richer, this same reasoning would justify weighting the impacts of present individuals according to their wealth, what is rarely done.[5] Conventional models assume that future individuals will be richer. This induces the idea that it is not profitable to make efforts in the present to reduce emissions that will affect future people (with a much smaller marginal utility).[6] However, this argument obviates the fact that the countries that are creating most of the problem are rich countries, while the ones that will suffer most severely are poor countries. Actually, climate change is already affecting poor countries with an increasing frequency of anomalies and climatic disasters. It is, at least, doubtful that the poor of the future will be in much better condition than the rich of the present; even more so if devastating effects of climate change on their ecological and socioeconomic systems are allowed. If the argument of marginal utility is used coherently, then when comparing costs and benefits, it should be taken into account that the hypothetical renouncement of bigger growth that might involve a stricter emissions control, should be in charge of the richest countries (main emitters), while climate change mitigation would facilitate that the conditions of life in the poor countries are not made worse.

Certainly, neither the argument of decreasing marginal utility nor the pure time preference justify the application of a constant time discounting, as if the individuals originating the problem and the ones suffering it were the same individuals, richer every time.

[5] Azar (1999) introduced equity weights and showed that, if the loss of a human life in a poor country is given the same monetary value as in a rich country, the result is a greater “optimal” reduction both in rich countries and in total than in conventional models.

[6] According to Schelling (1995), if in the future everybody is better off, the greater marginal utility would be the one of present poor people and it would be more efficient to increase their standard of life. Neumayer (1999) argues that a lower time discounting would be inconsistent with intergenerational equity, since he believes that the future will always be richer.

3.2. The Hicks-Kaldor compensation criterion and valuation problems

Conventional cost-benefit analysis is based on the Hicks-Kaldor compensation criterion, accordingly, a project is socially profitable if it is hypothetically possible that the ones that gain could compensate the ones that lose (Kaldor criterion), or if it is not possible that the ones that lose could pay to the ones that gain for not undertaking the project (Hicks criterion). If the present value of the benefits is greater than the present value of the costs, then it is assumed that those who benefit from the project can compensate those that are harmed by it, improving their initial situation (potential Pareto-improvement). If compensation was paid, everybody would improve and a net gain for society would occur (actual Pareto-improvement). However, whether this compensation occurs or not is irrelevant for cost-benefit analysis, it simply assumes that gains compensate loses, without taking into account who gains and who loses.

In ordinary evaluations, cost-benefit analysis without compensation can be justified if it is assumed that the marginal utility of a monetary unit of costs has the same social value as a monetary unit of benefits (Lind, 1997). Another justification is that, if there are many small projects everybody gains on the average. As Lind states, the ethical validity of these arguments depends on the initial distribution being judged as correct. In climate change, both the magnitude of the impacts and the very unequal distribution between those that gain and those that lose would invalidate these justifications. Moreover, it would be incorrect to talk about value-free or objective results.

In the case of climate change, the Hicks-Kaldor criterion assumes that a hypothetical monetary compensation between current individuals and future individuals (from the next 50 to 200 years) is feasible. But, currently, there are no institutions in place to make sure that this fund will find its way into the hands of its corresponding beneficiaries. The practical possibility of doing a monetary compensation for climate change is nonexistent. The central logic of cost-benefit analysis fails to make sense in the intergenerational context: it is not possible for those that “win” to compensate those that “lose” (there is no potential Pareto-improving change).

Another issue to consider is if monetary compensation is sufficient. Accepting that a monetary compensation is valid requires making very strong assumptions, such as perfect substitutability and non-existence of irreversibilities, issues that are not clear at all. Climate change might cause irreversibilities and catastrophes and some goods and processes non-susceptible of being compensated can be destroyed. There are also many relevant factors that are at least questionable that could be traduced into the monetary valuations of real or hypothetical markets. In decisions affecting elemental rights, such as the basic conditions of life of future generations, the compensation criterion might not be acceptable.

In general, when applying the Hicks-Kaldor criterion, the models assume that everything can be valued in monetary terms, although they only partially take into account the goods and services without a market. However, the implicit assumption of perfect substitutability between any types of goods is not scientifically based, but rather based in faith or the will of having easily tractable models. The compensation criterion also implies to price human lives, which, in itself, requires assuming that the method for determining its value is correct and that money in rich countries can be compared with lives in poor countries (Azar, 2000), what again implies a determinant value judgement.

Conventional analysis assumes that values are known, static, and exogenously determined. It is easy to value a toothbrush, but how can one value the extinction of half of the species? People do not have well articulated values about ecosystems, analysts assume that they do (and that they can be extrapolated to other places and periods) and the values assumed in the studies determine the preferred policies (Lave y Dowlatabadi, 1993).

The problem of climate change violates the assumption of marginal changes and the income effect in the valuations is very important, thus the cost-benefit analysis based in marginal measures is not appropriate. In addition, the willingness-to-pay measure is often used instead of the willingness-to-accept measure (e.g. Fankhauser, 1994; Pearce et al., 1996). There is important empirical evidence that counters neoclassical theory, showing these valuations to be very different, even in the case of small income effects. In contingent valuation studies, the quotient between willingness-to-accept and willingness-to-pay is from 2 to more than 10. In the case of climate change, the income effect is significant, which causes the willingness-to-pay to be much smaller than the value of the compensation people would accept. In addition to the income effect, there is the endowment effect (Kahneman and Tversky, 1979), which implies than loses are more weighted than gains. The difference between willingness-to-pay and willingness-to-accept can also be due to the consideration of some goods as inalienable. These explanations, and the empirical evidence that supports them, indicate that it is incorrect to use one measure when it is not the one stated by the problem, and even less so in a problem with the great magnitudes of climate change. Benefited and harmed people are placed in different areas and belong to different generations. This is particularly serious when the harmed ones are those that have less resources, which again, raises serious ethical questions.

Different regions, populations, and cultures, as well as different generations are affected in differing ways by climate change, and in some cases they value the same goods in a different way (Lave and Dowlatabadi, 1993). Who is being represented in the models' valuations? It does not make much sense to face the problem as if there were only one decision-maker, as the analysis which maximize a utility function ad infinitum (e.g. Nordhaus, various years), without taking into account the different perceptions of who gains and who loses in the process of maximization.

Conventional analysis assumes that present individuals have the right to pollute and that this is profitable if the higher economic growth that could be achieved is greater than the valuation of future harm. The countries that are most affected by climate change are, with all probability, the poor ones, while the main responsibility and the only ones that have resources to act fall to the rich countries. These countries have an ecological debt with the rest of the world and with future generations, since they have appropriated and made an unsustainable use of an environment that belongs to all present and future individuals. It is not justifiable, under any acceptable concept of equity or justice, that the poor have to suffer the ecological burden that involves the greater development of rich countries.

3.3. The distribution of rights in conventional analysis

Conventional economic analysis assumes the premise that the Earth and all its resources, including the climatic system, belong to the present, and that it has the right to do with them whatever it pleases, including the right to destroy them. It assumes that the only valid valuations are those of markets, where neither future generations nor present poor people can bid. But, is it legitimate to assume that they do not have any right? Considering that the same existence of future generations depends on the present preferences that can be expressed in real or hypothetical markets seems ethically corrupt!

The models assume that there exists the natural right to pollute, thus without obligation to compensate to those that suffer the consequences of this pollution. From this perspective, Hamaide and Boland (2000) try to overcome the limitation of Hicks-Kaldor criterion searching ‘Pareto-optimal’ solutions where everybody wins thanks to effective compensation. Their solution suggests that poor countries, the most benefited by mitigation policies, pay an economic compensation to China and the United States so that they control their emissions. In spite of the neutrality that conventional analysis tries to convey, it is undeniable that it is laden with strong value judgements that are ethically questionable and politically unacceptable.

The potential compensation implicit in optimization analyses consists of the payment by the affected of the future in order that the present incurs the “costs” of controlling its emissions. The optimal level is achieved when the so-called “marginal cost” of reducing emissions equals the present value of the “marginal benefit” experienced by future generations. That is to say, it states the hypothetical payment of a compensation by future generations in order to avoid the present destroying the necessary conditions for life in the future. Moreover, the compensation would be from poor to rich countries.

Furthermore, stating the problem as costs for the present and benefits for the future can facilitate the approval of policies unfavorable to the future, since usually, a phenomenon is more valued when it is considered as a loss than when it is considered as a gain (Kahneman and Tversky, 1979). This can also affect the chosen discount rate. As Mohr (1995) states, the ambiguity of the time preference depending on whether it refers to costs or benefits, leads to that, according to how the problem is presented, the citizens can be persuaded to agree with a particular opinion. The worst thing is that the result is often presented as the “scientific” one.

There are strong arguments for questioning the ethical validity of conventional analysis and the application of the (hypothetical) compensation to climate change. It is clear that for a more transparent analysis the more than questionable value judgements that are hidden behind the optimization analyses should be made explicit.

3.4. The point of view of sustainable development

The most popular definition of sustainable development states that it is the "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987, p. 43). A development complying with this definition would not allow the present to use resources in a way that jeopardizes the opportunities of the future. This implies recognizing the rights of future generations to enjoy a global ecological and economic capacity non-diminished in relation to the one we presently enjoy. In other words, the Earth and its resources, including climatic system, belong not only to the present rich people, but also to all (present and future) individuals. Using this view, the biased position of conventional analysis would not be correct when it argues about the "costs" that involves to the present reducing (or not excessively increasing) its greenhouse gas emissions in order to yield some "benefits" for future generations. The issue is to deal with the limitation of uncontrolled emissions growth, recognizing the rights of future generations so that their ecological and socioeconomic system does not deteriorate further. This is not to "give" anything to future generations, but rather to stop taking away something that, from the sustainable development perspective, they are entitled.

Present generations have the responsibility to study how their performance will affect the climate and environment that will be enjoyed by future generations and which is the most efficient way of respecting their rights. There are strong ethical, moral, deontological or contractual arguments for affirming that this would be a more legitimate starting point for the analysis of climate change policies. Section 5 states some of the issues to be considered for an analysis consistent with sustainable development.

4. Some additional limitations, biases, and omissions

The problems of the models used for determining the appropriate mitigation policies go beyond the limitations of conventional analysis. In general, both optimization and cost-benefit analyses incorporate value judgements, omissions, and arbitrary assumptions about factors that critically affect their results. The problem is that the biases they introduce always follow the same pattern: they tend to undervalue the loses and overvalue the economic gains of climate change, and hence lead to the recommendation that either emission control should be mild, or that there should be no control, at least in the short term.[7]

First, they tend to make quite optimistic assumptions about the virtues of economic growth. Current models usually assume high rates of future economic growth justifying it by past growth, without taking into account the negative environmental effect of this growth. This leads to the application of a greater discount rate (because of decreasing marginal utility of consumption) and to assume a greater capacity of adaptation, thus considering less serious the impacts caused by climate change.[8]

Another bias is highlighted by Schultz and Kasting (1997). The integrated assessment climate-economy models are based in pre-industrial CO_2 uptake rates. These undervalue the life of CO_2 in the atmosphere as they do not appropriately consider the saturation of carbon sinks. Consequently, the maximum concentrations of CO_2 in the atmosphere and the persistence of global warming are underestimated. In order to forecast absorption rates, carbon cycle models should consider the previous history of CO_2 emissions.[9] In the same sense, Price (1995) argues that Nordhaus (1994) overestimates the ocean's absorption of CO_2.

The climatic models employed in the studies are continuous and do not reflect the discontinuities that might occur. They assume that the change in CO_2 atmospheric concentrations is smooth and marginal (which could be reasonable) and then "deduce" that climate change and their impacts will be smooth and marginal (Pizer, 1996). This involves making an important qualitative leap, ignoring issues such as saturation of sinks, and the possible changes in equilibrium and discontinuities that might cause drastic changes. Oceanic currents and the atmospheric system could

[7] Chapman and Khanna (2000) casts doubts about the wisdom of most sophisticated (and costly) studies being financed by energy institutions (with the remarkable exception of Nordhaus), which could explain the biases, as they are interested parties.

[8] However, the models rarely consider the possible positive economic effects associated with the control of emissions, such as the "double dividend" (see e.g. Pearce, 1991), or the development of new sectors.

[9] Schultz and Kasting (1997) obtain greater "optimal" reductions than Nordhaus (1994).

change to alternative equilibrium causing rapid and extreme changes, with catastrophic impacts in some cases. The non-lineal character of climatic dynamics is often denied, perhaps for obtaining easily tractable models. Moreover, estimates generally do not take into account the effect of the rate of change: the greater the rate the greater the impact. They do not take into account either the effects of changes in climatic variability (IPCC, 2001b). Conventional evaluations (e.g. Nordhaus' studies) also ignore to a great extent the negative effects of global warming on ecosystems (Howarth, 1996).

Most models assume that uncertainty is small and manageable (Weyant et al., 1995). In climate change many interactions occur between complex natural and social systems in which little is known. Not recognizing the levels of uncertainty and ignorance in the models lead to erroneous results that should not be qualified as "optimal". Moreover, these models ignore the possibility of extreme phenomena, or simply assign them a negligible probability, when in fact both the possible results and their corresponding probabilities are ignored. A factor that should be important in decision-making is not taken into account, which biases the result towards a lower emissions control.

Most analysis (including the ones by Nordhaus) overlook that, besides their impact in greenhouse effect, emissions control has other significant associated positive effects (secondary benefits). The reduction in the particles that result from the combustion of fossil fuels (such as SO_x, NO_x and COV) would lead to a reduction in pollution and the resulting enhancement of health and well-being. If this were taken into account, the control of emissions as well as the rate of reduction would be greater than the one that most analyses indicate (Ekins, 1996).

Several studies (e.g. Nordhaus and Yang, 1996; McKibbin et al., 1999; Nordhaus and Boyer, 1999; Hamaide and Boland, 2000) assume a negative or very low cost of reduction in poor countries and greater marginal costs of reduction in richer countries. The result is that, in order to achieve "global efficiency", the greater reduction should be made in poor countries. However, there is no theoretical or empirical basis for these assumptions (Chapman and Khanna, 2000). It is obvious that focussing control efforts in the third world would not lead to a very ambitious environmental policy.

Many studies also assume that even if there were no controls, a peak in greenhouse gas emissions would occur, from which these emissions would diminish. This is known as the environmental Kuznets curve hypothesis, according to which the environmental problem would disappear in the long term thanks to economic growth. Empirical evidence for this hypothesis concerning greenhouse gases tends to refute it, especially in the case of CO_2 (see e.g. Roca et al., 2001). Even if the hypothesis was true, the delinking between environmental pressure and economic growth would occur at levels too high for income and emissions, which does not reduce the urgency of applying environmental policies (Selden and Song, 1994; Stern et al., 1996). Moreover, present forecasts of future emissions are less optimistic than the ones used in these models (IPCC, 2000).

Most models assume that technical change is exogenous. Important annual improvements in energy efficiency are assumed (reductions in the energy demand per unit of product) independent of the impact of energy prices. Chapman and Khanna (2000) argue that between 1980 and 1996 energy intensity has been constant at a global level, with a reduction in rich countries and an increase in poor countries. Therefore, past experience would not justify the application of such assumptions. On the other hand, the possibility of a technical change induced by the response of firms to market conditions is, in general, not considered. There is evidence that an important part of technical change in the energy sector is endogenous (Grubb and Walker, 1992). Grubb and Köhler (2000) analyze the consequences of assuming an important induced technical change and they conclude that it tends to accelerate emissions control because the same mitigation develops the knowledge that allows an emissions control at lower cost and causes it to be very cheap in the long term.

Lastly, it should be pointed out that, for the moment, the impacts associated with the upper margin of warming estimated by the last report of the IPCC (2001b) has not yet been investigated. This also leads us to presume that the adequate reduction in emissions has been underestimated, even from the point of view of conventional models.

5. Towards an analysis coherent with sustainable development

The obligation of respecting the rights of future generations jointly with the limitations of conventional models impose an analysis of mitigation policies incorporating constraints in terms of climate change impacts. Given the impossibility of establishing an adequate compensation because of the uncertainties, ignorance, substitution problems, irreversibilities, non-marginal changes and time discounting inconsistency that climate change involves, the obligations of the present should lead to the "stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system", ultimate objective of the United Nations Framework Convention on Climate Change. In this way, guaranteeing their ecological opportunities, a fair treatment to the future would be ensured. Moreover, the respect of the rights of the future should be done in a way that involves the lowest sacrifice to the present.

Various papers have investigated the cost-effective paths of reduction of emissions in order to achieve different concentration targets. Unfortunately, most of them have not been overly concerned with how to determine what level of concentration is appropriate or consistent with sustainable development and neither have they worried about incorporating all the information that is relevant for decision-making, but were presented as simple technical cost-minimization exercises. Some of the problems that these models embody have been shown above and many of them suggest an even smaller reduction of emissions in the short term than cost-benefit analyses (e.g. Richels and Edmonds, 1995). Hammitt (1999) shows, for different concentration targets, a lower aggressiveness in the short term of these models. This has been explained by the following reasons: avoiding the premature retirement of existent capital stock; existence of carbon sinks, which means that the proportion of CO_2 remaining in the atmosphere is lower for earlier emissions; technological progress, which causes cheaper emission reduction in the future; and because of discounting, which makes the present value of costs lower if reduction is delayed (Wigley et al., 1996). Nevertheless, these explanations are quite questionable. It has already been shown that if technical change is induced and not exogenous as is it usually assumed, it is better to reduce emissions earlier (Grubb and Köhler, 2001) and short term policies would accelerate the development of the changes that would reduce mitigation costs. Grubb (1997) casts doubts on the appropriateness of postponing the renewal of capital and argues that this could involve greater total costs, since it would also postpone the innovation which reduces mitigation costs. In these results also influence that, in general, the impacts of different warming rates as well as the discontinuities and possible changes of equilibrium are not taken into account. If these factors were considered, one would question the appropriateness of prematurely saturating carbon sinks. In addition there is the aforementioned inconsistency that involves applying discounting to intergenerational problems. In summary, a targets or objectives approach should not involve a lower reduction than conventional cost-benefit analyses. Rather on the contrary, if the objective has to be consistent with sustainable development.

One of the approaches that has gone further in the search of an integrated assessment coherent with sustainable development is the tolerable windows approach, explained in Petschel-Held et al. (1999), Yohe (1999) and Dowlatabadi (1999). Starting from the constraints in tolerable changes, it imposes limitations in the rate of warming, the level of concentrations, the path of emissions and finally the policy instruments. It can consider different types of information and does not require translating everything into monetary terms. Through this approach, the obligation of preserving the natural environment for future generations could become quantitative constraints in policies.

Several authors, including Hasselmann (1999), have criticized that the targets approach is inconsistent with determining the optimal allocation of all resources. However, his criticism is based on the premise of conventional analysis, that of not recognizing any right to the future. Even Nordhaus (1997), author of the most influential neoclassical optimization model, sees a clear opposition between economic optimality and sustainable development and suggests the previous introduction of targets for the permissible levels of climate change.

Nevertheless, a serious limitation of most cost-effectiveness analyses is that they give up taking into account the short and medium term impacts, focusing only in the final long-term objective. This could delay the reduction of emissions, since higher short term emissions could be compensated with greater reductions in the long term, which does not happen in the cost-benefit approach (Grubb, 1997). The short and long term sacrifices that the reduction involves are accounted for under both analyses, but the short and medium term consequences of emissions are only considered under cost-benefit analysis. This is inconsistent with sustainable development. The introduction of limits to ensure that climate change impacts do not jeopardize the global capacity of future generations should not involve avoiding the considerations of the different impacts that might occur and to try to appropriately allocate the resources. Any climate change impact on the future implies an alteration of the endowment to be enjoyed by future generations and so should be considered in the determination of the adequate policies. The structure of rights that sustainable development implies turns any impact that diminishes the capacity of the future into an obligation for the present. In this sense, once any intolerable (and so non-susceptible of being compensated for) impact is avoided, the compensation for any ecological debt acquired with the future for present contamination should be accounted for and made effective, and monetary compensation could not be the most appropriate one. The necessary information for determining which impacts would be intolerable should be collected and the institutional framework created to be able to establish and articulate the adequate compensations in order that they can be achieved in the future.

In summary, conventional cost-benefit analysis is not appropriate for a problem with the extreme uncertainty and severity of climate change. There is ignorance about many costs and benefits and it is not very feasible for many impacts to be expressed in monetary terms. All variables relevant for society should be taken into account, not only those that can be valued in money. It would be more reasonable to try to obtain solutions that could be considered satisfactory using all the available information, than the pretension of conventional analysis of obtaining optimal points at the margin through models based on unreal assumptions and that are unable to show all the facets of the problem.

6. Conclusions

This paper presented a critical review of the limitations of the evaluation models used in the problem of climate change. A first conclusion is that the application of cost-benefit criteria loses legitimacy in the climate change context as many of the assumptions that justify it are violated. Most studies have also tended to incorporate value judgements and arbitrary assumptions and even to obviate a good part of the relevant information, which contributes to bias the results towards the conclusion that climate change is not a problem requiring urgent action.

Conventional analysis assumes that there is the natural right to pollute or even destroy the climatic system. The present paper refuses this premise and suggests an alternative approach in which the future is entitled to a non-deteriorated climatic system, and therefore the present has the obligation to avoid or to compensate any alteration of it.

An appropriate assessment of the policies to apply in climate change also requires incorporating the growing knowledge about the phenomenon. In the evaluation of adequate policies, all relevant information should be taken into account without using model complexity to hide value judgements and arbitrary assumptions about questionable factors or hiding elements that are determinants for decision-making. On the contrary, the analysis should serve to clarify what are the trade-offs and the choices that can be made. The integrated assessment should serve for increasing the knowledge of the phenomenon through the same process. The gathering of information, the study of alternative policies, the estimation of impacts and the knowledge of the critical parameters should lead to a better position for making informed decisions.

Even if the models determining the adequate policies (consistent with sustainable development) are designed, it is necessary to ensure that there are institutions in place that can establish emissions control and be responsible for the transfer of adequate compensations. It does not make much sense to produce models in search of adequate global policies, if there are no institutions with the capacity to apply them. These institutions should be able to achieve reduction commitments by different countries according to their capacity and their responsibility in the problem. It is urgent that the adoption of international commitments go beyond the Kyoto Protocol and the Bonn 2001 agreement. It is imperative that these institutions have the capacity to sanction atmosphere free-rider practices and eliminate the incentives that cheat the agreements. The disappearance of credible sanctions (besides the wide consideration of natural carbon sinks) of the Bonn agreement seriously questions its effectiveness.

Finally, people of poorer countries are suffering and will continue to suffer the most severe impacts of climate change, while some countries have occupied and are occupying much more environmental space in terms of historic CO_2 emissions than would correspond to their population (Alcántara and Roca, 1999). Rich countries have a moral obligation to pay the ecological debt acquired in having expropriated and destroyed the right of poor countries to a non-deteriorated climate. From an ethical point of view, in the long term, the only justifiable distribution of rights is the one that gives the same right to any human being — present or future. The distribution according to current per capita emission, as established in the Kyoto Protocol agreements, strongly favors those that have contributed the most to the problem, which is clearly unfair.

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