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Reducing Methane Emissions: The Other Climate Change Challenge

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Contents

Summary

Climate change studies show that it is vital to reduce atmospheric concentrations of greenhouse gases massively in the coming decades in order to limit the global average temperature rise ultimately to 2 or 3 degrees Celsius and prevent the occurrence of irreversible phenomena such as the melting of permafrost. To achieve these targets, climate experts construct scenarios estimating the changes in the atmospheric concentrations of the various greenhouse gases, and determine the maximum levels that these concentrations should reach. Climate change policy targets are then set in terms of greenhouse gas emission reductions. In order to simplify the overall assessment of the impact of emissions of these different greenhouse gases (carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O, etc.) on global warming, the international community has adopted rules of equivalence to make it possible to take into account the emissions of non-CO_2 greenhouse gases with one single unit: the tonne of CO_2 equivalent (t CO^2 eq). This is achieved by using the "Global Warming Potential" (GWP) indicator which indicates the ratio of the respective climate impacts of a pulse emission of the greenhouse gas considered (CH_4 for example) over a given period of time to a pulse emission of CO_2 of the same volume in the same year. A reference period of 100 years was defined; this therefore means that, in terms of climate impacts, the emission of 1 tonne of CH_4 is "worth" the emission of 21 tonnes of CO_2.

The study presented in this document shows that the widespread use of this equivalence to calculate not only past emissions, but also anticipated future emissions and emissions avoided over a period in the past or future, has led to the climate impact of CH_4 emissions being underestimated because the GWP of CH_4 varies considerably depending on the period under consideration (from around 100 for the first few years to 21—or 25 according to the most recent assessment—for a 100-year period). This underestimation is accentuated even more if the respective impacts of avoided emissions of CO_2 and CH_4 are compared, whether they are avoided permanently or for a limited period of time. Thus, comparing the climate impact of a 30% reduction in global CH_4 emissions between 2010 and 2030 and of a 40% reduction in CO_2 emissions over the same period shows that the CH4 programme is 50% as effective as the CO_2 programme in 2030, around 40% in 2050 and 20% in 2150. Contrary to widely accepted belief, the effect of rapidly implemented CH_4 emission reduction measures is highly significant in short- and medium-term climate strategies.

The breakdown of global methane emissions by sector is as follows: agriculture (38%), energy systems (33%), household waste landfills and waste water treatment (23%), and industry and forest fires (6%). The different possibilities for reducing these emissions are presented for each sector. The short-term (one or two decades) reduction potential is thus estimated to be around 30%. Interesting possibilities to go beyond this exist but they require more in-depth research and studies. Concrete CH_4 emission reduction programmes are presented: capturing methane from landfills in France and comparing this with certain CO_2 emission reduction programmes; a comparison of Germany's and France's recent methane emission reduction policies; reducing methane emissions from the energy system in Tunisia and from household waste in Mexico; and the expected results of reducing methane emissions by capturing coal mine firedamp under China's Climate Plan for 2010. In the current context of fossil fuel prices, a significant proportion of the emission reduction potential (household waste and a large share of leaks from energy systems) can be cost-effectively harnessed simply by recovering the methane for energy production purposes. For the remaining potential, regulatory or fiscal incentives are crucial. Seeking to massively and rapidly decouple methane emissions from GDP growth should therefore provide a major opportunity for emerging countries to put themselves on a path towards controlling increases in their greenhouse gas emissions in the medium term (20 to 60 years). This is particularly true since the corresponding investments can often be recouped by providing a new energy service (farm biogas, for example) or switching away from fossil fuels.

Both the under-estimation of the effects of methane emission reductions and the wide range of sector-related greenhouse gas emission reduction programmes and measures lead us to reconsider whether it is appropriate to set emission reduction targets expressed in a single unit (t CO_2 eq) and,

consequently, whether it is relevant to implement a "global carbon market" based specifically on the use of this unit. Both the importance of the time factor when assessing the respective effects of CO_2 and CH_4 emission reductions, and the extraordinary range of policies and technologies—in terms of implementation conditions and economic costs—lead us to recommend that separate emission reduction targets be set for these two greenhouse gases, and that international climate negotiators begin to draw up country-by-country priority action programmes and define arrangements for their implementation on the basis of a preliminary analysis of the largest and most easily harnessed sectoral reduction potentials.

Résumé

Les études sur l'évolution du climat montrent qu'il est impératif de réduire massivement la concentration des gaz à effet de serre dans l'atmosphère durant les toutes prochaines décennies si l'on veut limiter à terme le réchauffement atmosphérique à 2 ou 3 degrés et éviter l'apparition à court terme d'irréversibilités comme la fonte du permafrost, par exemple. Afin d'atteindre ces objectifs, les experts du climat établissent des scénarios d'évolution des concentrations des différents gaz à effet de serre et déterminent des limites à atteindre pour ces concentrations. Les objectifs des politiques de lutte contre le changement climatique sont ensuite fixés en termes de réduction des émissions de gaz à effet de serre. Afin de permettre une simplification de l'appréciation globale de l'incidence des émissions des différents gaz (gaz carbonique CO_2, méthane CH_4, oxyde nitreux N_2O, etc.) sur le réchauffement climatique, la communauté internationale a adopté des règles d'équivalence permettant de comptabiliser les émissions des gaz autres que le CO_2 en une unité commune, la tonne équivalent CO_2 (teq CO_2), en utilisant le "Potentiel de réchauffement global" (PRG), indicateur qui fournit le rapport des effets respectifs sur le climat, pour une période donnée, d'une émission ponctuelle du gaz considéré (CH_4 par exemple) à une émission ponctuelle de CO_2 de même masse la même année. Une période de référence de 100 ans a été fixée et l'on aboutit ainsi à dire que, en termes d'effet sur le climat, l'émission de 1 tonne de CH_4 "vaut" l'émission de 21 tonnes de CO_2.

L'étude présentée dans ce document montre que l'utilisation généralisée de cette équivalence pour mesurer les émissions constatées mais aussi les émissions futures envisagées ou les émissions évitées sur une période passée ou future conduit à une sous-estimation des effets sur le climat des émissions de CH_4 car son PRG varie très rapidement avec la période considérée (de 100 environ pour quelques années à 21 ou 25 selon les plus récentes évaluations pour une période de 100 ans). Cette sous-estimation est encore accentuée si l'on compare les effets respectifs d'émissions évitées – soit de façon pérenne, soit pour une durée limitée - de CH_4 et de CO_2. C'est ainsi que la comparaison des effets sur le climat d'une réduction de 30% des émissions mondiales de CH_4 entre 2010 et 2030 et d'une réduction de 40% des émissions de CO_2 sur la même période montre que l'efficacité du programme CH_4 atteint environ 50% de celle du programme CO_2 à l'horizon 2030, environ 40% à l'horizon 2050 et 20% en 2150. Le poids d'une action rapide de réduction des émissions de méthane est donc loin d'être négligeable dans les stratégies de lutte contre le réchauffement climatique à court et moyen terme, contrairement à l'opinion couramment admise.

Les émissions mondiales de méthane se répartissent de façon sectorielle entre l'agriculture (38%), le système énergétique (33%), les déchets ménagers et le traitement des eaux (23%), l'industrie et les feux de forêt (6%). Les différentes possibilités de réduction de ces émissions sont présentées pour chaque secteur. On évalue ainsi que le potentiel de réduction à court terme (une ou deux décennies) est de l'ordre de 30%. Des possibilités intéressantes existent pour aller au-delà et nécessitent des études et des recherches plus approfondies. Des exemples concrets de programmes de réduction des émissions de CH_4 sont présentés : captage du méthane des décharges en France et sa comparaison à certains programmes qui réduisent les émissions de CO_2 ; comparaison des politiques récentes de réduction des émissions de méthane de l'Allemagne et de la France ; réduction des émissions de méthane du système énergétique de Tunisie et des ordures ménagères du Mexique ; résultats escomptés des réductions des émissions de méthane par captage du grisou des mines de charbon dans le Plan climat de la Chine à l'horizon 2010. Une part

importante des potentiels de réduction d'émissions (ordures ménagères, une proportion importante des fuites des systèmes énergétiques) est économiquement mobilisable au simple titre d'une valorisation énergétique du méthane dans le contexte actuel des prix des combustibles fossiles. Pour l'autre part, des incitations réglementaires ou fiscales sont indispensables. La recherche d'un découplage massif et rapide de la croissance des émissions de méthane et de la croissance du PIB devrait donc constituer une opportunité majeure pour les pays émergents sur le chemin d'une maîtrise de la croissance de leurs émissions de GES à moyen terme (20 à 60 ans). D'autant que les investissements correspondants peuvent être souvent rentabilisés par la fourniture d'un service énergétique nouveau (le gaz à la ferme, par exemple) ou d'un substitut aux combustibles et carburants fossiles.

La sous-estimation des effets de la réduction des émissions de méthane comme la très grande variété des programmes et des actions qui permettent la réduction des émissions de gaz à effet de serre en fonction du secteur considéré, conduisent à reconsidérer la pertinence de la fixation d'objectifs de réduction exprimés en une unité unique (la teq CO_2) et, en conséquence, la validité de la mise en œuvre d'un « marché unique du carbone », basé précisément sur l'utilisation de cette unité. L'importance du facteur temps pour apprécier les effets respectifs des réductions d'émission du gaz carbonique et du méthane, comme l'extraordinaire variété des politiques et des technologies – en termes de conditions d'application comme de coût économique – conduisent à recommander de définir des objectifs de réduction des émissions distinctes pour ces deux gaz et d'engager les négociations climat sur la définition et les conditions de mise en œuvre de programmes d'action prioritaires pays par pays, sur la base d'une première analyse des potentiels sectoriels les plus importants et les plus accessibles.

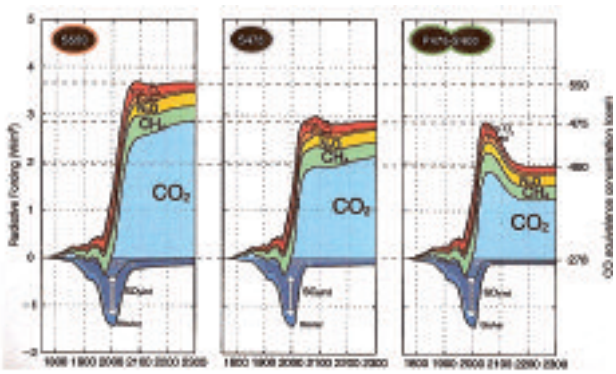
1. Climate Risk

The latest report by the Intergovernmental Panel on Climate Change (IPCC) shows that it is both necessary and urgent to act to avoid the worst in terms of global warming. The IPCC Working Group I shows, first, that if the average temperature of the atmosphere were to rise to 2.5 or 3 degrees Celsius above what it was in the pre-industrial era, there would be a major risk that irreversible phenomena would occur such as the melting of permafrost, the diminishing of the role forests and the oceans play as carbon sinks, etc. In their turn, these phenomena could bring about an inescapable change in the climate. For this reason, regions such as Europe have set themselves the objective of not exceeding two degrees of warming. But, what does a target such as this mean for greenhouse gas concentrations and emissions? Comparing a large number of scenarios described by the IPCC provides partial answers to this question. Indeed, we know that there are numerous gases that intensify the greenhouse effect when emitted: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), chlorofluorocarbons (CFCs), etc. Each of these "greenhouse gases" (GHGs) present unique characteristics in terms of their absorption of radiation and the length of time they persist in the atmosphere after being emitted.

In their simulation models, climate experts studying climate change use emission and concentration data for each of these gases in different evolution scenarios to anticipate changes in the climate. When summarising their results, they habitually present them using the notion of "equivalent CO_2 concentration" for all greenhouse gases. This concentration is the concentration of CO_2 that would on its own have the same effect on the climate at a given moment in time as all the greenhouse gases present in the atmosphere at that same time. A comparison of these scenarios show that the "2ºC" limit has a good chance of being respected only if humanity ultimately manages to stabilise the concentration of all greenhouse gases at approximately 400 or 450 parts per million by volume of CO_2 equivalent (ppmv CO_2 eq). The analysis also shows, however, that exceeding this target concentration by too much during the intermediary period of 2020 to 2100 (beyond 475 to 500 ppmv) would risk making it definitively impossible to attain this target. Indeed, "radiative forcing"—that is to say, the terrestrial radiation generated by these over-concentrations of GHGs that is expressed in Watts per square meter—runs the risk of causing irreversible climate change.

Figure 1 illustrates this. The scenarios shown on the left and in the centre lead to very high probabilities (if not the certainty) of the Earth's temperature increasing by more than two degrees Celsius. Under the scenarios shown on the right, which peak at 475 ppmv CO_2 eq (or approximately 3 Watts per sq. meter of radiative forcing) during the current century and then fall to approximately 400 ppmv CO_2 eq (or 2 W/m^2) after 2100, there is a strong possibility of avoiding an increase of more than two degrees Celsius.

Figure 1. Contribution to Net Radiative Forcing of the Various Components of Radiative Forcing in Trajectories Leading to a Stabilisation at 400 to 550 ppmv CO_2 eq.



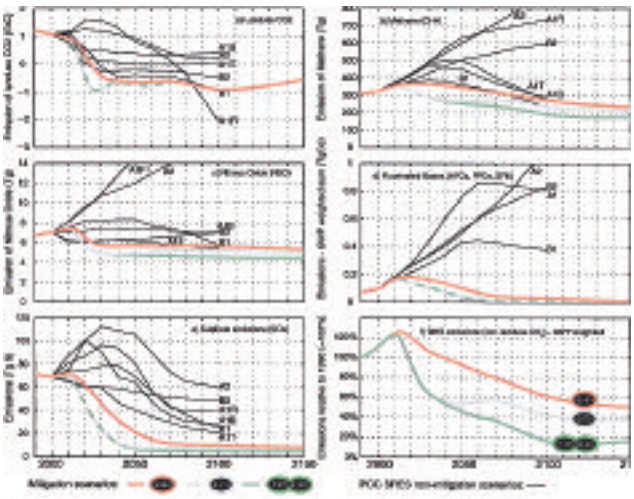
Note: The upper edge of the zones represents anthropogenic radiative forcing. The net cooling generated by the direct and indirect effects of various aerosols (SOx and biomass) is indicated by the lowest negative curve. The arrow indicates the considerable uncertainty in regard to forcing due to SOx. Source: Malte Meinshausen, 2006.

2. Where Are We Today?

In its latest report, the IPCC Working Group I gives relatively precise information on changes in ppmv CO_2 eq concentrations and radiative forcing over the last decades. In 2005, CO_2 concentration was 379 ppmv, for additional radiative forcing of 1.66 W/m^2 compared to the pre-industrial period. The other GHGs are said to have contributed 1 W/m^2 of additional radiative forcing, and the negative effect of aerosols was approximately 1 W/m^2. This gives a total additional radiative forcing of 1.7 W/m^2 (with a large error bar due to the uncertainty as to the role of aerosols). However, since the year 2000, global emissions of all GHGs—measured according to the equivalency rules given by the IPCC (1 kg of CH_4 equals 21 kg of CO_2, 1 kg of N_2O equals 310 kg of CO_2) which will be analysed in detail in chapter 3.2—have been increasing at a rate of 3% per year and show no signs of slowing. Under these conditions, one can clearly see that the maximum acceptable concentration (and the additional radiative forcing of approximately 3 W/m^2) is in danger of being exceeded well before 2050.

Therefore, climate change is an issue for a much sooner future than policy makers generally imagine, as Figure 2 clearly shows. In particular, the last chart (lower right) summarising the others gives a clear view of the global emission (in t CO_2 eq) trajectory to follow in order to avoid uncontrollable changes to the Earth's climate. This figure highlights the very short-term need to reach a turning point and an approximately 40% reduction in t CO_2 eq global emissions in 2030 compared to 1990, whereas these emissions are currently growing much more quickly than the noted curve of 475-400 ppmv. These few figures show the magnitude of the challenge in terms of short-term **reduction dynamics.**

Figure 2. Evolution of the Various Greenhouse Gas Emissions for the Trajectories of the "550", "475" and "400" ppmv CO_2 eq Scenarios in Figure 1.



Source : Malte Meinshausen, 2006.

1. GHG emissions have already increased by nearly 24% between 1990 and 2004.

3. Margins of Manœuvre

3.1 Current Status

Since the pre-industrial period, the concentrations of the primary greenhouse gases due to human activity (carbon dioxide, methane and nitrous oxide) have evolved as shown in Table 1.

Table 1. Atmospheric Concentrations in Volume and Lifetime of the Principal Greenhouse Gases

Greenhouse Gas	Pre-Industrial Concentration	Concentration in 2004	Δ %	Lifetime in the Atmosphere
Carbon Dioxide CO_2	278 ppmv	380 ppmv	37 %	roughly 200 years
Methane CH_4	0.7 ppmv	1.7 ppmv	143 %	roughly 12 years
Nitrous Oxide N_2O	0.275 ppmv	0.311 ppmv	13 %	roughly 300 years

Source: IPCC Fourth Assessment Report, Working Group I "The Physical Science Basis", Changes in Atmospheric Constituents and in Radiative Forcing, 2007.

The concentration of methane is increasing the fastest, followed by CO_2. Global GHG emissions in 1990 and 2004, measured in physical units, are given in Table 2.

Table 2. Greenhouse Gas Emissions in Units of Mass

Principal Greenhouse Gas Emissions	1990 (Mtonnes)[2]	2004 (Mtonnes)	Δ (Mtonnes)	Δ (%)
CO_2	29,000	37,600	8,600	29.50 %
CH_4	325	355	30	9.20 %
N_2O	11	12	1	9.10 %
CFCs	ε	2ε		50 %

Source: IPCC Fourth Assessment Report, Working Group I "The Physical Science Basis", Changes in Atmospheric Constituents and in Radiative Forcing, 2007.

However, in the vast majority of publications destined for policy makers, global emissions appear in a different form. Indeed, to allow simplified overall understanding of the impact of emissions of these various gases on climate change, the decision was made to use rules of equivalency that allow emissions of GHGs other than CO_2 to be measured in a common unit: the tonne of CO_2 equivalent (t CO_2 eq). This is commonly defined based on the relative impact of each gas on global warming compared to that of CO_2, an effect that is calculated over a fixed period of time following the emission of each gas, e.g. 100 years. This impact on the climate is identified as the cumulated radiative forcing associated with a given gas over the entire period considered. For this, the IPCC proposed the notion of "global warming potential" (GWP). GWP indicates the relative contribution to global warming, during a fixed period (e.g. 100 years), of a single emission at the start of the period of one kg of a given greenhouse gas compared to the contribution over the same period of a single emission of one kg of CO_2. The GWPs calculated for different intervals of time take into account the different lifetimes of the various gases in the atmosphere.

2. Mtonne: million tonnes

3. Gt CO2 eq = billion tonnes of CO2 equivalent.

Saying that the GWP of methane over a period of 100 years is 21 (as the IPCC indicates) is to say that a single emission of one tonne of CH_4 has an impact on the climate equivalent to that of a single emission of 21 t of CO_2 over the 100-year period following the emissions. The convenience of using the t CO_2 eq as a single unit very quickly led to its widespread use, whether for observed emissions, envisaged future emissions (under the aims of climate policies notably), or cumulated emissions over a given (past or future) period. For this reason, in most publications accessible to policy makers, emissions are given in "CO_2 equivalent" (CO_2 eq) using the 100-year equivalencies for various greenhouse gases established by the IPCC, which gives us Table 3 for the years 1990 and 2004.

Table 3. Greenhouse Gas Emissions in Tonnes of CO_2 Equivalent

Emissions in Gt CO_2 eq[3]	1990	2004	Δ	Δ %
CO_2	29	37.6	8.6	29.50 %
CH_4	6.8	7.5	0.7	9.20 %
N_2O	3.4	3.7	0.3	9.10 %
CFCs	0.2	0.4	0.2	50 %
Total	39.4	49.2	9.8	25 %

Source: IPCC Fourth Assessment Report, Working Group III "Summary for Policy Makers", 2007.

The meaning of these figures in CO_2 eq is as follows:
- The 1990 column gives the contribution of various gases to global warming during the 100 years that followed 1990, therefore between **1990 and 2090**.
- Similarly, in the 2004 column, the figures express the contribution of various gases to global warming from **2004 to 2104.**

The 1990 and 2004 columns in Table 3 cannot, therefore, be compared directly since they express effects over different timeframes.

Finally, one should note that Table 3 would show very different results if it were given in the 20-year (instead of 100-year) CO_2 equivalents also proposed by the IPCC as early as 1994 (in its 1994 report) and still valid (but long forgotten) today. Indeed, with this valid rule to express the influence of various greenhouse gases over the 2004-2024 period, CH_4 emissions would have been given as 22.1 Gt eq and 35% of total global emissions, compared to 15% in Table 3, and CO2 emissions would have accounted for 60% instead of 76%. Nevertheless, a quick glance at the figures in Table 3 clearly shows why CO_2 emissions retain nearly all of policy makers' attention. First, CO_2 accounted for nearly three fourths of total emissions in 2004 when using this convention. In addition, they are increasing most rapidly, with the exception of CFCs whose role is, nevertheless, marginal.

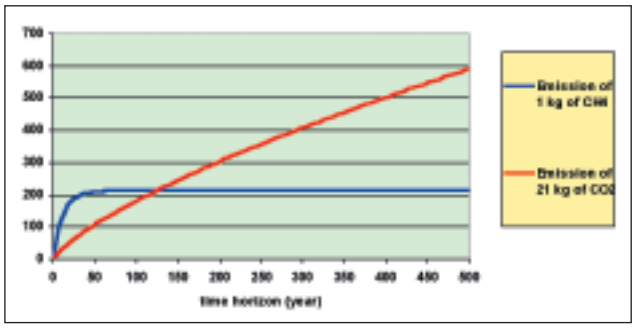
The logical conclusion is that CO_2 must be tackled in absolute priority. Greenhouse gas emission reduction policies are therefore almost exclusively focused on carbon dioxide and largely ignore methane and nitrous oxide, neither of which are the subject of any large-scale international plans. The total lack of reference to these gases—in the French national consultation to reform environmental policy (the *Grenelle de l'Environnement*) as in the deliberations of the European Council of Ministers for the Environment meetings or the latest UNDP report on global warming—is highly indicative of this negligence. Yet, we have seen that the deadline for concern is considerably closer than thought—not after 2100 but well before 2050, perhaps 2030 or 2040. It is therefore necessary to qualify this first analysis and more specifically estimate the real effects of the emission of various greenhouse gases, not only by the 22nd century but also much sooner (2030 or 2040)—deadlines for which the warming potential of some of these gases is very different. This is especially true for methane whose global warming potential increases very quickly when the observation period is shortened.

3.2 Reasons Why the Short- and Medium-Term Influence of the Effect of Methane on the Climate Is Under-Estimated[4]

Three reasons of varying importance contribute to the under-estimation of the short- and medium-term effects of methane emissions on the climate.

The first reason, and the most important, is due to the fact that the "global warming potential of methane" (defined by the IPCC as the relative contribution to global warming over a fixed period of a single emission of methane at the start of the period compared to an emission of the same quantity of carbon dioxide) varies very rapidly with time. Indeed, methane's capacity to absorb infrared emissions is nearly 100 times that of CO_2, but it resides in the atmosphere for a much shorter amount of time than CO_2 (roughly one decade, compared to a century). This results in a very rapid variation over time of methane's GWP as shown in Figure 3 which gives the evolution of the cumulated effect on the climate over time of a single emission, in year 0, of 1 kg of methane and of one emission that same year of 21 kg of carbon dioxide, which are seen as equivalent.

Figure 3. Integrated Radiative Forcing at Different Years of One Emission in Year 0 of 1 kg of CH_4 and 21 kg of CO_2



Source: Author's calculation.

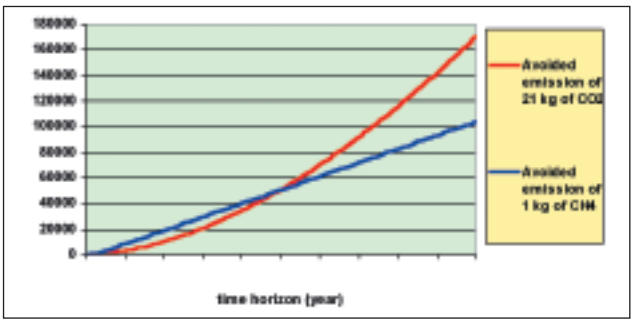
The second, more minor, reason is due to the fact that the IPCC has refined its analysis of the absorption phenomena for the various gases, which has lead to increasing methane's 100-year GWP from 21 to 25.[5]

Table 4 gives the GWP values over time.

The last reason is due to the very definition of GWP, which deals with the relative cumulated consequences over time of a single emission at a given moment in time of a given greenhouse gas and the same quantity (in mass) of CO_2. This definition is generally not operational for policy makers in charge of setting up emission reduction policies. Indeed, in the vast majority of cases, the measures envisaged are destined to be permanent or at least very long-lived:[6] insulating a house, building an electric power plant that does not emit CO_2 to replace a coal plant, etc. are measures that have long lifetimes. In addition, policy makers generally implicitly consider that the end-of-lifetime renewal of an emission-reducing installation will be done with identical or more effective means when it comes to emissions. Therefore, policy makers can measure the effect on the climate at a given time horizon based on the cumulation, year after year, of measures generally seen as permanent.

4. A detailed article on this subject can be found in Appendix 1.
5. Under current CO_2 concentration conditions. It should be noted, however, that the radiative efficiency of CO_2 decreases as its concentration increases. If one hypothesises a short-term continuation of rising CO_2 concentration, the GWP would be higher than the GWP calculated by the IPCC.
6. With the noteworthy exception of the quota trading scheme that does not differentiate between measures based on their lifetime.

Figure 4. Cumulative Radiative Forcing of an Avoided Emission of 1 kg of CH_4 and of 21 kg of CO_2 per Year (Permanent) Starting in Year 0



Source: Authors' calculations.

Over the short term, the under-estimation by 21 of the effects generated by the use of the GWP by policy makers is very high (a factor of 3.9 at 20 years and 2.7 at 50 years). It is still 1.9 at 100 years and only reaches a value of 1 at 250 years. Then, the situation is inversed and one sees an over-estimation of the effect of CH_4 which reaches a factor of 1.6 at 500 years. These curves, along with the table showing the changes in the GWP of methane over time, clearly show both the short- and medium-term interest of actions to lower methane emissions and the limits of such actions because, over the long- and very long-term, the effect of this reduction loses its interest compared to lowering CO_2 emissions.[7] That is to say that methane reduction policies should not replace the indispensable CO_2 reduction policies on which the long-term depends. Methane policies must therefore be seen, rather, as supplements that present the considerable advantage of helping in the short term maintain the climate within limits that avoid excessive risks of irreversible phenomena occurring.

Table 4. GWP Value of CH_4 According to Time Horizon (year of emission: 0)

Year	5	10	15	20	25	30	35	40	45	50
GWP	101	90	80	72	64	58	53	49	45	42
Year	55	60	65	70	75	80	85	90	95	100
GWP	39	37	35	33	31	30	28	27	26	25
Year	105	110	115	120	125	130	135	140	145	150
GWP	24	23	23	22	21	21	20	19	19	18

Source: Authors' calculations.

3.3 The Magnitude of the Stakes and Consequences of a Global Methane Emission Reduction Policy in the Coming Decades

To gain an awareness of the magnitude of the stakes at world level, it is interesting to analyse two types of scenarios which have the objective of lowering the emissions of CO_2 or of CH_4 in proportions required by the current objectives on global warming limitation.

In the first scenario, S1, the emissions of the GHGs other than CO_2 are maintained at their 2004 values, and CO_2 emissions alone are reduced by 40% compared to their 2004 level, which represent a reduction by 20 Gt. This reduction is to take place over the 2010-2030 period in a linear progression of 1 Gt of CO_2 per year. The second scenario, S2, consists of keeping the emissions of the GHGs other than methane at their 2004 values, and reducing methane emissions as much as can reasonably be envisaged between 2010 and 2030.

We shall see below (chapter 4) that a reasonably accessible reduction of CH_4 emissions in 2030 (or even before) can be estimated at approximately 30%, or 110 Mtonnes of the 355 Mtonnes emitted worldwide in 2004 (see table 6). This reduction corresponds to a credible programme simultaneously targeting the capture of a large amount of the methane emitted by landfills and sludge from sewage

7. A sample comparison of the short- and medium-term effects of two CH_4 and CO_2 emission reduction programmes can be found in Appendix 2.

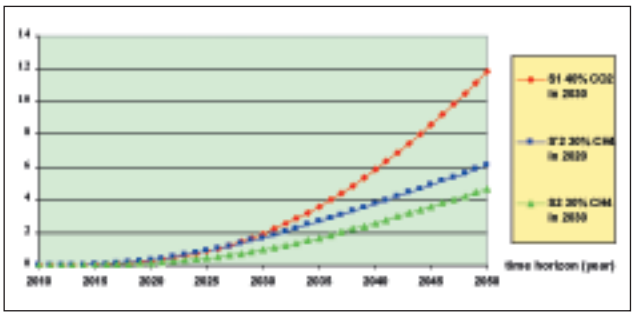
treatment plants, the partial recycling of manure and slurry from stock farms, and the reduction of leakage from energy systems (mines, transportation networks, oil wells).

A programme such as this can be envisaged over the same period of time as the first, with a linear progression of 5.5 Mtonnes per year from 2010 to 2030. However, the same type of methane emission reduction actions can also be envisaged over the much shorter term, by 2020, with a progression of 11 Mtonnes per year because, unlike the CO_2 reduction programme, it does not require the construction or modification of heavy infrastructures. This is scenario S'2.

Based on the calculations in the preceding paragraph, one can then easily evaluate the cumulated effect on the climate of these different strategies from their rollout until a given time horizon, here 2050. Figure 5 compares these three scenarios.

One can draw several important lessons for action from this figure. The first lesson is that methane reduction actions, no matter what their dynamics, are far from marginal in relation to actions that can be taken on CO_2 alone. If the two programmes CO_2 (40%) and CH_4 (30%) are conducted at the same pace until 2030, the effectiveness of the CH_4 programme attains 49% of the CO_2 programme in 2030, and even 44% in 2040, and 39% in 2050. The second lesson concerns the dynamics of these programmes. If the CH_4 reduction programme can be accomplished by 2020, which is plausible, its efficiency would be greatly improved: 88% in 2030, 64% in 2040, and 57% in 2050.

Figure 5. Comparison of the Effects on the Climate (Avoided Integrated Radiative Forcing at Various Horizons) of a 40% Reduction in Global CO_2 Emissions from 2010 to 2030 and a 30% Reduction in CH_4 Emissions from 2010 to 2020 or to 2030.



Source: Authors' calculations.

Table 5 supplements this information by comparing, over the 2020-2050 period, a wider range of strategies.

Table 5. Comparison of the Effects of Emission Reduction Programmes on the Climate

Avoided Cumulative Radiative Forcing (W-year/m²)	2020	2030	2040	2050
CO_2 : 20 % in 2020	0.3	1.8	4.6	8.4
CO_2 : 20 % in 2030	0.15	1	2.9	5.9
CO_2 : 30 % in 2020	0.45	2.7	6.9	12.5
CO_2 : 30 % in 2030	0.21	1.45	4.35	8.8
CO_2 : 40 % in 2030	0.3	1.93	5.8	11.85
CH_4 : 20 % in 2020	0.15	1.1	2.5	4.1
CH_4 : 20 % in 2030	0.1	0.63	1.75	3.15
CH_4 : 30 % in 2020	0.3	1.7	3.95	6.1
CH_4 : 30 % in 2030	0.15	0.95	2.6	4.7

Source: Authors' calculations.

These results confirm that the effect of rapidly implemented methane emission reduction measures, even relatively modest ones, is never negligible in **short- and medium-term** strategies to fight global warming. Of course, the effectiveness of this reduction wanes over time: the effectiveness of the 30% reduction of CH_4 by 2030 programme compared to the 40% CO_2 programme at the same time falls to 39% in 2050, 25% in 2100, and 18% in 2150. This last point justifies the need for proactive action to reduce CO_2 emissions, which remains vital to ensuring that the **long-term target** is attained.

4. Methane Emissions

4.1 Breakdown of Methane Emissions by Sector and by Region

Overall, methane emissions in the atmosphere are estimated at 500 Mtonnes per year, 360 of which from anthropogenic sources. The distribution by sector and by region of these anthropogenic methane emissions is not known with great precision for two reasons. First, it is more difficult to estimate CH_4 emissions than CO_2 emissions, the majority of which come from fossil energy whose amounts and emissions are easy to measure. Second, the international community has not paid much attention to CH_4 emissions. In particular, there is only information on them for 1994 in the various inventories of non-Annex I countries, parties to the Climate Convention. There is, however, overall indications that provide approximate magnitudes of these emissions for the breakdown by sector of activity and major region, as indicated in Tables 6 and 7.

Table 6. Breakdown of Methane Emissions by Sector (1994)

CH_4	Million tonnes (Mtonnes)	Percentage
Agriculture (stock farming and rice cropping)	135	38
Energy System (leakage, firedamp, etc.)	118	33
Household Waste and Water Treatment	82	23
Industry and Forest Fires	22	6
Total	357	100

Source: IPCC Special Report on Emission Scenarios. Climate Change 2001, Working Group I: The Scientific Basis.

Table 7. Indicative Regional Breakdown of Methane Emissions (1990)

1990	OECD Countries	Asia (non-OECD)	North Africa + Latin America	Countries in Transition + Sub-Saharan Africa	Total
Percentage	24 %	37 %	22 %	17 %	100 %

Source: IPCC Special Report on Emission Scenarios. Climate Change 2001, Working Group I: The Scientific Basis.

From the standpoint of sectors of activity, agriculture dominates, with the preeminence of stock farming, except in Asia where rice cropping accounts for two-thirds of agricultural emissions. Leakage from energy systems comes next. The third largest source consists of emissions from household waste landfills. The last, primarily due to deforestation and slash-and-burn practices in the savannah, is important in African countries and Latin America.

4.1.1 The Agricultural Sector (38%)

Agricultural sector emissions have been growing slightly since 1990 (<10%). Stock farming contributes nearly 60% of these emissions, and the rest come primarily from flooded rice cropping. The methane expelled by ruminants (bovines, sheep) is the product of incomplete digestion during gastroenterological fermentation, especially when the animals are fed proteaginous plants (soy in particular). For instance, one cow can emit between 100 and 500 litres of methane per year (70 to 350 g) depending on what it eats. To this one adds emissions from the excrement of all stock farming animals (ruminants, pigs, poultry, etc.) that continues to decompose by producing more or less methane depending on its surroundings. In Western countries, for which we have relatively precise statistics, we see that two-thirds of stock farming emissions come from animals' enteric fermentation and one-third from manure and slurry. In France, for instance, stock farming methane emissions in 2005 amounted to 1,950 kilotonnes, 1,325 kilotonnes of which from enteric fermentation and 625 kilotonnes of which from animal excreta. In rice cropping, two types of bacteria act: anaerobic bacteria that develop in the absence of oxygen, and aerobic bacteria that develop in the presence of oxygen. Anaerobic bacteria produce methane, while aerobic bacteria consume it. The irrigation techniques frequently used in rice cropping primarily favour the development of anaerobic bacteria, and only very little of the methane they produce is absorbed by aerobic bacteria. As a result, a large quantity of methane is produced and released into the atmosphere. The production of one kilo of rice corresponds to an emission of 0.1 kg to 0.12 kg of methane. Because of this, rice cropping is the second largest producer of methane worldwide, producing 60 million tonnes per year, right behind ruminant farming. However, alternative irrigation techniques, in particular seasonal drainage, could be used to limit this problem.

4.1.2 The Energy Sector (33%)

Energy sector emissions come from coal mines (firedamp), losses from oil and gas fields, leakage in the transport system and natural gas distribution, and, marginally, from the automobile sector. Worldwide, these emissions have increased by more than 15% since 1990. Here too, the distribution of these various emissions by fossil source and by region of the world is relatively little known.

Coal

Evacuating and eliminating the methane that comes from coal seams is the principal method to reduce fugitive emissions from coal. Most of these emissions take place in mines, with some residual emissions from post-extraction handling and processing activities. There are two types of coal mines: surface mines and underground mines. The specific emission rates due to coal extraction depend primarily on the relative shares of surface and underground mining in a given country's total coal production. Methane emissions from surface mines are usually ten times less than those from underground mines. With the latter, the quantity of emissions tends to increase with the depth of the mine. With both types of mines, the emission potential is determined by the coal's gas content. Some of the gas can remain in the coal until it is burnt, but most (60% - 75%) is rejected during extraction. Emissions from coal handling are linked to the type of mine that produced the coal, and are primarily associated with crushing.

Coal mine emissions can continue after coal production has ceased in the mines (that is to say, in abandoned mines). In general, the quantity of emissions falls rapidly after underground coal production has ceased but, in some cases, methane emissions from neighbouring seams can be considerable and continue for years. Coal residue and piles of waste coal are only a limited source of methane emissions. There are practical solutions to fight emissions from coal mining and handling, notably the use of degassing wells and either conserving or flaring the gas produced, or the use of catalytic combustion chambers installed on underground mine ventilation system outlets (Shi Su *et al.,* 2005).

There are no recent precise country statistics on methane leaks associated with mining. The example of China can, nevertheless, give us an idea of their magnitude. In its 1994 report to the UNFCCC, China declared 7 Mtonnes of fugitive CH_4 emissions for a coal production of approximately 1,100 Mtonnes. In 2006, production—at 2,400 Mtonnes—had more than doubled. From this, one can therefore infer

approximately fifteen Mtonnes of CH_4 emissions. This order of magnitude is compatible with the objectives set by China in its national plan to fight the greenhouse effect by 2010 (Mark Tuddenham, 2007), which envisages capturing and recovering 10 million tonnes of methane from its coal mines. As China produces approximately 40% of the world's coal,[8] one can estimate the scope of fugitive methane emissions in the coal sector worldwide at 30 to 35 million tonnes of CH_4.

Oil and Natural Gas

The principal sources of fugitive emissions from oil and gas plants are system leaks, evacuation and flaring procedures, losses due to evaporation (storage and handling of products, notably in the case of losses from flash distillation), and accidental discharges or equipment malfunction. Accidental discharges can be substantial sources in the case of well kick, pipeline breakage, oil tanker accidents or tank explosions. Another source of emissions is the migration of gas to the surface around the outer well wall and leakage in abandoned wells.

Overall, the quantity of fugitive emissions from oil- and gas-related activities is not proportional to the level of production or output of systems. It is more closely linked to the quantity, type and age of infrastructure, the characteristics of the hydrocarbons produced, processed or handled, and industrial practices. Emissions from evacuation and flaring depend on the volume of activity, operating practices, opportunities for on-site use, economic access to markets, and the local regulatory context. With the exception of oil refineries and integrated tar sand extraction and conversion operations, oil- and gas-based systems are characterised by a large number of small factories and plants rather than by a few large ones. Among other things, while it is easy to obtain reliable information on the largest installations, the numerous small installations are generally the ones responsible for the majority of fugitive emissions, and it is much more difficult to obtain information on them. With natural gas, for example, estimates of total gas network losses vary within a range of 1% to 2% depending on the country and source. The International Energy Agency (IEA) estimates losses at 10 Mtonnes (2%) for Gazprom in Russia, the largest natural gas producer with 25% of world production. In the United States, the second largest natural gas producer in the world (19%), fugitive emissions are 5 Mtonnes of CH_4 (1%).[9] Extrapolated to a production of approximately 2,000 Mtonnes of CH_4, fugitive methane emissions from the gas system would therefore be between 35 and 40 million tonnes of CH_4.

Fugitive oil emissions also vary greatly from country to country. In the United States, leaks are minor: approximately 1.5 Mtonnes of CH_4, compared to the country's production of approximately 350 Mtoe/year. In Saudi Arabia, however, fugitive emissions linked to the oil system were 3.5 Mtonnes in 1990, for a production of approximately 420 Mtoe/year,[10] and thus more than double in proportion to production. Based on this, losses from the upstream sector can be estimated at between 4 and 10 Mtonnes per Gtoe of oil, with an average of close to 8, or approximately 30 Mtonnes of CH_4 for current oil production, to which one must add the fugitive emissions of 10 to 15 Mtonnes of CH_4 from the refining and storage chain. All in all, fugitive emissions are distributed in roughly equal proportions among the three principal sources of fossil fuels, in the neighbourhood of 40 Mtonnes of CH_4 each.

4.1.3 Landfills and Water Treatment (23%)

More than 85% of the emissions in this sector come from household waste landfills, and the rest come from sludge in water treatment plants. These emissions increase rapidly with the urbanisation and economic development of emerging countries. This is the case, for example, in Mexico where methane emissions increased by a factor of 2.1 between 1990 and 2002.[11] In highly developed countries such as the United States, CH_4 emissions from household waste landfills release as much CH_4 as ruminants' enteric fermentation (6 Mtonnes of CH_4). In Europe (27 countries), CH_4 emissions from landfills still account for approximately 4 Mtonnes of CH_4 in 2008, despite the European directive in force on landfill methane recuperation (Skovgaard *et al.,* 2008).

8. BP Statistical Review of World Energy 2007.
9. Detailed inventory of US emissions (www.epa.gov/climatechange/emissions/usinventoryreport.html)
10. First national communication of the Kingdom of Saudi Arabia submitted to UNFCCC, 2005.
11. unfccc.international_reports/non annex_1_natcom/items/2979php

In emerging and developing countries, the situation varies greatly according to the level of development and urbanisation. In a country like Saudi Arabia, which is very urbanised and very little agricultural, 75% of CH_4 emissions come from household waste management (600 Kt).[12] In Argentina, which also had 600 Kt of emissions in 2000, household waste is responsible for only 15% of CH_4 emissions, which are largely dominated by enteric fermentation in stock farming (2,400 Kt).[13] This is also the case in Brazil where landfill emissions in 1994 accounted for only 10% of methane emissions from stock farming.[14]

4.2 Methane Emission Reduction Potential

Considerable potential to reduce or control methane emissions worldwide in the short and medium term can be identified based on current achievements and practices in various sectors and countries. In the energy sector, one can envisage, subject to more precise country-by-country analysis, capturing approximately 40% of emissions in the short term. China's official objectives for firedamp in its plan to fight climate change by 2010, with savings of 10 Mtonnes of CH_4 out of the approximately fifteen currently emitted (65%), allow one to extrapolate a minimum reduction of 20 Mtonnes of CH_4 worldwide. Similarly, by setting the reasonable medium-term (2030) global objective of average fugitive emissions of still 30% more than those of the United States for oil (6 Mtonnes of CH_4 per gigatonne of oil) and gas (1.3% of leaks), one could limit emissions to approximately 25 Mtonnes of CH_4 for the gas sector and 25 Mtonnes for the oil sector. All in all, one can therefore reasonably envisage to reduce world energy system emissions by 50 Mtonnes in the medium term. In the household waste sector, there are numerous methods to reduce methane emissions: covering landfills and capturing methane (modelled on numerous sites in Europe), incineration (as long as environmental and sanitary problems are resolved), use of methanation reactors, or waste composting. These solutions all make it possible to cut residual methane emissions to a few percentage points. CH_4 emissions linked to urban waste could reasonably be reduced by approximately 40 to 45 Mtonnes from the generalisation of these methods which have already been amply tested in Northern European countries.

In agriculture, rice production (approximately 600 million tonnes) is the source of approximately 60 million tonnes of CH_4 emissions. However, numerous studies and experiments show that these emissions are heavily dependent on cropping methods. In particular, draining twice during the cropping cycle makes it possible to reduce methane emissions considerably (80%). In the rice-producing countries with the highest yields (more than 50 quintals per hectare) that account for half of the world's rice production (United States, China, Vietnam, Japan), one can reasonably envisage a reduction of approximately 20% in the short term if farmers there receive financial incentives. In the field of stock farming (approximately 80 million tonnes of CH_4), one cannot envisage capturing the methane emitted directly by ruminants, except perhaps marginally for battery-reared animals. Experiments are, nevertheless, underway on cattle feeding to lower their methane emissions. But, it is probably still too early to envisage programmes that could be applied to a very large percentage

12. Cf. footnote 11.
13. Second national communication of Argentina submitted to UNFCCC, 2007.
14. First national communication of Brazil submitted to UNFCCC, 2004.
15. See, for example, Roger and Le Mer, 1999.
16. In countries such as China, where average per-hectare yields exceed 60 quintals, financial incentives to reduce CH_4 emissions from rice production through better agricultural practices have every chance of being very effective. Indeed, a 20% reduction in emissions per hectare represents 1.2 tonnes of CH_4—the current equivalent of 25 tonnes of CO_2 using the IPCC's current coefficient. Valued at 20 dollars per tonne of CO_2, this represents the considerable incentive of 500 dollars per hectare and 85 dollars per tonne.

of herds worldwide. However, processing manure and slurry, whose emissions today account for approximately 25% of world emissions from stock farming (20 Mtonnes of CH_4), can be an important source of emission reductions. Effective techniques to do so exist and numerous manure and slurry methanation plants function in industrialised countries[17] and developing countries (China, India, Vietnam, etc.).

The size of these installations varies greatly, ranging from fermentation vats with capacities of a few hundred litres, to a few dozen square metres suited to the needs of small family farms, to installations with capacities of several thousand square metres capable of processing the agricultural waste of several large farms producing several million square metres of gas and several million kWh per year. The waste-to-energy conversion of this methane makes most of these operations profitable in the context of current energy prices. The reasonably actualisable potential of this resource in the short term (approximately 25% to 50%) represents an additional reduction of world methane emissions of 5 to 10 Mtonnes of CH_4.

Table 8 summarises orders of magnitude for the possibilities identified.

Table 8. Potential Magnitudes of World Methane Emission Reductions in the Short and Medium Term (10 – 20 years) by Sector

Sector	Reduction Potential Mtonnes (Mt)
Coal	-20
Oil	-15
Natural Gas	-15
Landfills	-40 à -45
Agriculture (Rice)	-6 à -10
Stock Farming Waste	-5 à -10
Total	-101 à -116

Source: Authors' calculations.

The reduction potential is therefore approximately 30% of current emissions (357 Mtonnes).

Beyond this, on the longer term, one can imagine the generalisation of methane-sober rice cropping practices, domestic animal feeding, the intensification of the fight against fugitive emissions from the energy sector, and the total eradication of methane emissions from household waste.

17. Basic data for farm biogas plants in Germany, July 2005, ATEE biogas club, www.biogaz.atee.fr

5. Illustrative Examples of Methane Emission Reduction Policies

A few examples of the consequences of concrete programmes and past or future policies, for both industrialised and developing countries, allow for more concrete understanding of the importance of reducing methane emissions in the fight against global warming in the short and medium term.

5.1 A Landfill Methane Capture Programme in France

In 2004, France emitted 2,980 kilotonnes (Kt) of CH_4. Most (1,560 Kt) came from agriculture, primarily enteric fermentation in ruminant farming. In second place were two sources of methane emissions: organic waste (570 Kt, 533 of which solid waste in landfills) and stock farming effluents (cattle and pig slurry, approximately 580 Kt). Finally, fossil energy combustion and fugitive fuel emissions accounted for 495 Kt of CH_4 emissions.

When it comes to landfills, French law encourages controlled landfills (Circular of March 1987) to recover methane (biogas) or at least burn it in flare pits. According to the ADEME (French Environment and Energy Management Agency), 10% of landfills in France were thus equipped in 1993, 25% in 1996, and 57% in 1997, with yields of approximately 60% in 1999, that could reach 80% in the 2000s. The inter-ministerial task force on the greenhouse effect estimated that a good landfill gas capture network would make it possible to reduce landfill emissions by nearly 100%. This gas is often wasted in France, whereas Canada, England and Italy have long utilised part of their landfill gas (Deneux, 2002).

Yet, some of these landfills in France are now equipped with systems (landfill covers, drainage tubes, and methane evacuation flues) that make it possible to collect nearly all the methane emitted and use it for energy purposes. The short-term (before 2015) generalisation of this procedure to all high-capacity French landfills would therefore make it possible to avoid most of the still considerable emissions from existing landfills, even if the dumping of some compostable waste were to continue over the medium or long term. It is this policy to definitively eliminate 400 kilotonnes of methane from the 500 kilotonnes currently emitted before 2015 that we propose to assess in terms of its effect on the climate at different time horizons[18] by comparing it to policies currently being decided or that could be envisaged in regard to CO_2 savings. In particular, we refer either to programmes for energy production without carbon emissions (nuclear, renewable), or energy efficiency policies. A first estimate of the investment needed for this programme leads to spending of a maximum of 1 billion euros.[19]

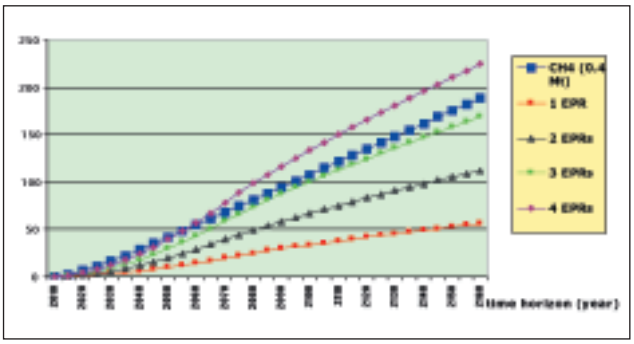
18. Excluding the possible energy use of the captured methane that could replace the use of a fuel that emits CO_2, or even methane and N_2O.

19. Authors' assumptions: a classic landfill cell of 10,000 m^2 and a depth of 20 m containing 200,000 m^3 of waste produces approximately 12,000 tonnes of CH_4 in 30 years. Covering the cell and the associated systems is estimated to cost one million euros, of which 0.5 to 0.7 for the covering (50 to 70 euros/m^2), for 400 tonnes/year. Thus, an investment cost of 2,500 euros per tonne of CH_4.

5.1.1 Landfill Methane Recovery vs. Nuclear Revitalisation

The proposed scenario is that of putting into service a certain number of 1,500 MW EPR reactors by 2020, with a unit investment cost of approximately 3 billion euros. Each reactor is capable of producing 10 TWh per year for 60 years. This electricity production replaces classic thermal production means (assuming that this substitution happens in the European energy context) and allows for carbon dioxide savings that vary in function of the source of the fuel used.[20] Figure 6 shows the consequences of these actions in terms of the integrated effect on the climate over different periods and makes it possible to compare them to the results of the methane policy. It shows that the integrated effects on the climate would be of the same magnitude over the next 150 years. The 4-EPR and 3-EPR curves frame the methane curve.

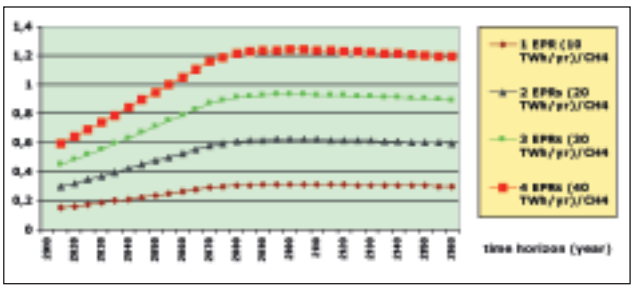
Figure 6. Cumulated Effects of the Methane Policy and the Policy of Replacing Gas and Coal Production (50/50) with EPRs



Source: Authors' calculations.

Figure 7 indicates the evolution over time of the effectiveness of the 1- to 4-EPR programmes relative to the envisaged methane programme. On this figure, we show the ratio of the ordinates from the previous figure, that is to say (1 EPR)/methane, (2 EPR)/methane, and so on.

Figure 7. Effectiveness of the 50/50 Electricity, Gas and Coal Replacement by EPRs Policies Relative to the Methane Policy



Source: Authors' calculations.

Figure 7 shows that the installation of 3 EPRs is unable to reach the effectiveness of the proposed methane policy over the period 2020-2150. The 4-EPR policy, however, achieves the effectiveness of the methane policy in 2055, and becomes 19% more effective than the methane policy from 2080 to 2160. If the EPRs replace combined cycle gas turbine plants, which emit less CO_2 (400 g/kWh), the results are similar but 5 EPRs would be needed to reach the effectiveness of the proposed methane policy.

5.1.2 Landfill Methane Recovery vs. an Old Housing Upgrading Programme

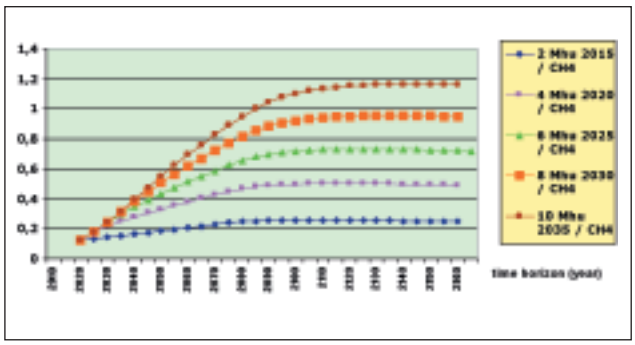
This is a heavy upgrading programme for old housing (built before the mid-1970s), proposed in the framework of the French national consultation to reform environmental policy (*the Grenelle de l'Environnement*) by the Négawatt Association. Its ambition is, over 40 years (2010-2050), to reduce average home energy consumption by 250 kWh/m^2 of primary energy, for a cost of approximately 20,000 euros per housing unit. This programme plans to renovate 400,000 housing units per year over 40 years, or 16 billion housing units by 2050, with average emission savings of 2.5 tonnes of CO_2 per unit[21] and a renovation lifetime of 60 years. Figure 8 makes it possible to compare this policy, between 2010 and 2035, to the landfill methane recovery policy. It

20. Assumptions: CO_2 emissions from coal electricity = 0.8 kg per kWh, emissions from gas electricity = 0.4 kg per kWh, emissions from CREs = negligible.

21. Assumption: Savings of 250 kWh of primary energy per m^2 per year, on pre-1975 housing units with an average size of 72 m2. In France, heating old housing accounts for 64% of fossil fuels (35% of gas, 25% of oil, and 4% of coal and the fossil fuel share of electricity).

shows that the methane policy has results of the same magnitude over the entire period as the renovation of 400,000 old housing units each year for 25 years.

Figure 8. Relative Effectiveness of Renovation Policies Compared to the CH_4 Policy

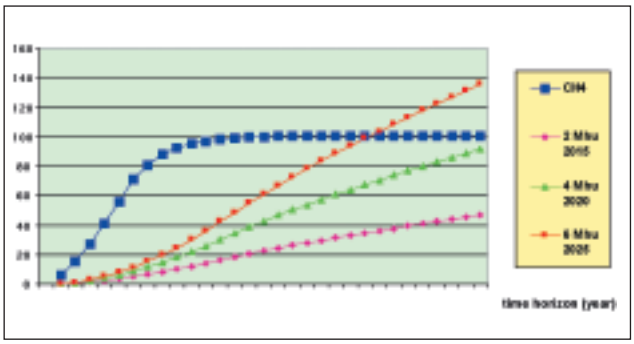


Source: Authors' calculations.

5.1.3 Sensitivity of the Results

It is interesting to complete this information by examining the sensitivity of the results to the lifetime of the policies set up. Accordingly, we hypothesise that the methane capture measures would have a reduced lifetime of 30 years (instead of being permanent), and maintain the hypothesis of a 60-year lifetime for the renovation measures. Figure 9 shows the results. The "6 million housing units" curve crosses the methane reduction curve in 2130, whereas it does not cross it under the permanent CH_4 reduction hypothesis. This example shows the importance that must be granted to methane emission reduction policies that have long—or even permanent—lifetimes. Such policies, when they are technically and economically feasible, have very interesting results in terms of effects over the coming decades and remain comparable to ambitious energy efficiency or energy substitution policies to the end of the century.

Figure 9. Cumulated Effects of a Methane Policy Rolled Out by 2015 (30-year lifetime) and Housing Renovation Policies (400,000/yr, 60-year lifetime)



Source: Authors' calculations.

5.2 The Medium-Term Consequences of Various Countries' Recent Public Policies on Methane

The methane policies rolled out in the recent past by various countries will have effects over the course of this century that are interesting to examine.

5.2.1 Germany and France

In France and Germany, the policies rolled out since 1990 have led to the changes in methane and carbon dioxide emissions given in Table 9.

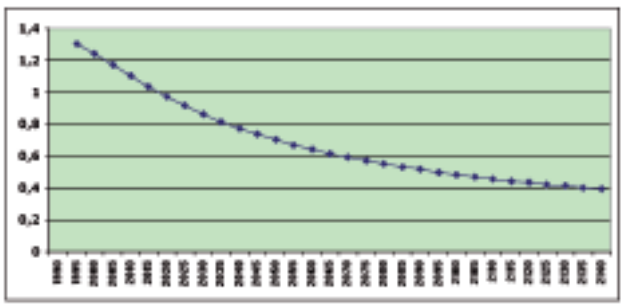
Table 9. CH_4 and CO_2 Emissions in Germany and France from 1990 to 2004

CH_4 (Kt)	1990	2004	Δ %
Germany	**4157**	**2376**	**-43**
Of which: Energy	*918*	*697*	*-24*
Agriculture	*1420*	*1100*	*-23*
Waste	*1820*	*577*	*-68*
France	**3243**	**2980**	**-8**
Of which: Energy	*495*	*454*	*-8*
Agriculture	*2130*	*1951*	*-8,40*
Waste	*576*	*543*	*-6*
CO_2 (Mt)	**1990**	**2004**	**Δ**
Germany	**976**	**839**	**-14**
France	**358**	**345**	**-4**

Source: Enerdata.

A very large difference between the two countries can be seen in the changes in methane emissions, regardless of sector: a more than 40% reduction over 14 years in Germany, compared to 8% in France. While the difference is relatively easy to explain for energy because of the partial abandon of coal in Germany and the closing of mines, in other sectors it is explained only by the two countries' different policies (e.g. waste treatment). Over the course of the period, Germany reduced its CO_2 emissions by 14%, France by 4%. We can estimate, for each of the two countries, their contributions to the fight against warming brought about by these reductions, *hypothesising that they will remain in effect until the end of this century.* This is the goal of Figures 10 and 11.

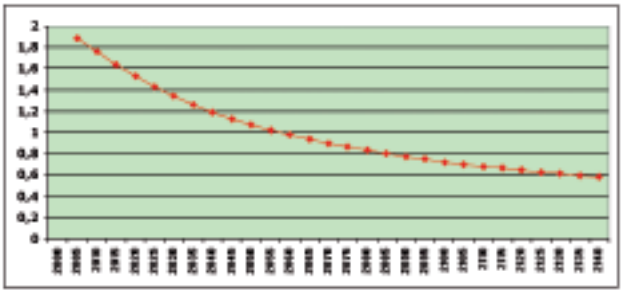
Figure 10. Comparative Effectiveness of Methane and CO_2 Reduction Policies in Germany from 1990 to 2005



Source: Authors' calculations.

In Germany, the methane reductions in 2005 have consequences analogous to those of the CO_2 reductions over the same period until 2020, and are still 70% of the latter in 2050. They fall to approximately 40% in 2150.

Figure 11. Comparative Effectiveness of Methane and CO_2 Reduction Policies in France between 1990 and 2005



Source: Authors' calculations.

In France, the methane reductions in 2005 have consequences better than those of the CO_2 reductions over the same period until 2070, and are still 60% of the latter in 2150. In both cases, the contribution of lowering methane emissions to the reduction in the overall radiative balance is far from negligible compared to CO_2 reduction—even in the case of Germany that had, during the same period, managed to lower its CO_2 emissions by 14% (1% per year).

5.2.2 Tunisia and Mexico

In all likelihood, these growing countries' CO_2 emissions will increase in the coming decades, even if they succeed in significantly reducing the energy density of their economies. It is not, however, inevitable that their CH_4 emissions follow the same trend if suitable programmes are set up. An examination of these countries' recent past is interesting to measure the impact of such policies on their future balances.

In Tunisia: Fugitive Emissions from the Energy System

In Tunisia, methane and CO_2 emissions from the *energy sector,* which accounted for 53% of the country's total GHG emissions mid-period (1997), evolved as shown in Table 10 over the 1990-2003 period

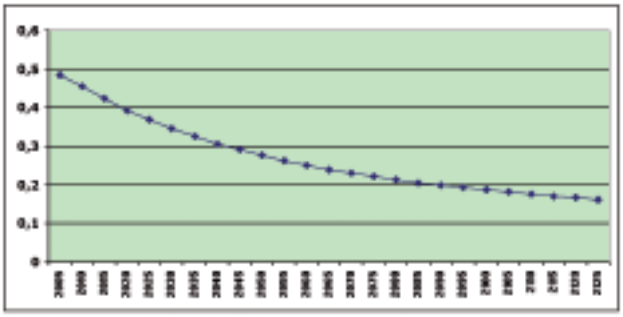
Table 10. Evolution of Energy Sector CH_4 and CO_2 Emissions in Tunisia from 1990 to 2003

	1990	1993	1996	1999	2003	Δ %
CH_4 (Kt)	46.4	46.6	55.3	66	85	83
Of which						
Fugitive Emissions	33.7	34.2	42.9	53.4	71.9	114
Other	12.7	12.4	12.4	12.7	12.9	1
CO_2 (Kt)	12 927	14 589	15 764	18 314	20 778	61

Source: Evolution of GHG Emissions Due to Energy in Tunisia 1990-2003, Ministry of Industry, Tunisia, December 2005

The rise in CH_4 emissions—much more rapid than CO_2 emissions over the same period—is almost entirely due to the growth in fugitive CH_4 emissions (7.2% per year) following the development of the country's natural gas fields. The relative influence of these new CH_4 and CO_2 emissions over the century, which are assumed to be permanent, is shown in Figure 12.

Figure 12. Contribution of Energy-Sector Methane and CO2 to the Intensification of the Greenhouse Effect from 1990 to 2003 in Tunisia



Source: Authors' calculations.

In 2050, the fugitive emissions from the years 1990-2003 should still contribute 28% of the impact of Tunisian energy system CO_2 emissions from the same period, which is far from negligible. It is therefore important that Tunisia, if it aims to reduce its contribution to global warming, undertake a proactive policy to eliminate these fugitive emissions as much as possible.

In Mexico: Landfill Emissions

From 1990 to 2002, carbon dioxide emissions increased by 28% and methane emissions by 34% in Mexico. This sharp growth in methane emissions is mostly due to the establishment over the period of household waste collection and landfill disposal systems and wastewater treatment plants as Table 11 shows.

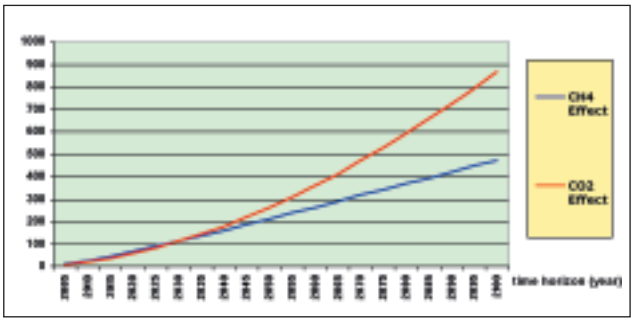
Table 11. Evolution of Mexico's CO_2 and CH_4 Emissions from 1990 to 2002

Mexico (Mtonnes)	1990	2002	Δ %
CO_2	283	393	28%
CH_4	4.5	6.8	34%
Of which			
Fugitive Emissions	1.57	1.85	18%
Waste and Wastewater	1.45	3	207%

Source : Third national communication of Mexico submitted to UNFCCC, 2006.

However, these measures—obviously indispensable from the sanitary standpoint—were not, it would seem, accompanied by sufficient provisions to capture the methane produced by the decomposition of organic matter in landfills and by wastewater processing. Figure 13 shows the impact of the emissions during this time on the intensification of the greenhouse effect during the century. In 2020, the effects of additional methane emissions are 15% greater than those caused by CO_2 pressure, equivalent in 2035, still 65% in 2075, and 54% in 2100.

Figure 13. Comparative Effects to 2100 of Additional CH_4 and CO_2 Emissions in 2002 Compared to 1990 in Mexico



Source: Authors' calculations.

5.3 An Example of a Future Programme: China's Climate Plan

China published its first national strategy to fight climate change on 4 June 2007. Elaborated by the National Development and Reform Commission (NDRC), China's National Climate Change Programme (NCCP) contains a series of measurements and numerical targets for 2010. In particular, those pertaining to energy can be summarised as shown in Table 12.

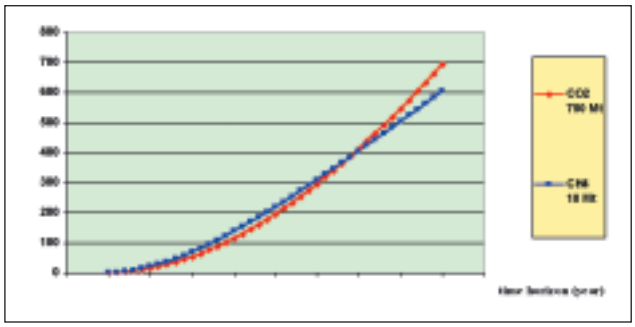
Table 12. Avoided GHG Emissions (in Mtonnes) in 2010 Due to the Provisions in China's National Climate Change Programme in the Field of Energy Production and Processing

Sector/Technology	Avoided Emissions in 2010 (Mtonnes)
Hydraulic	500 (CO_2)
Nuclear	50 (CO_2)
Thermal Power Plants	110 (CO_2)
CH_4 Recovery from Coal Mines	10 (CH_4)
Bioenergy and RNE	90 (CO_2)
Total	750 (CO_2), 10 (CH_4)

Source: Chine : énergie et émissions de gaz à effet de serre, Mark Tuddenham, CITEPA, 2007.

Figure 14 compares the consequences over time of the CO_2 and CH_4 policies described.

Figure 14. Medium-Term Consequences of the CO_2 and Methane Policies in China's NCCP



Source: Authors' calculations.

One can see that, until 2040, the mine firedamp capture policy is as effective as all the other energy diversification policies undertaken, and still 85% as effective in 2050. The success of this policy is therefore crucial in the medium term for this country where energy needs are growing rapidly. These retrospective and prospective examples show the importance and diversity of the options to fight climate change open to countries with highly diverse geographic, sectoral and economic characteristics when it comes to lowering methane emissions.

6. Economic Aspects

6.1 Two Logics

From the economic standpoint, the various technologies envisaged to reduce methane emissions have very different faces depending on whether the avoided methane emissions come from true methane savings (it is not emitted) or, on the contrary, from the capture and possible re-use of methane emissions seen as unavoidable. Indeed, in the first case, economic actors have no interest in making the necessary investments without incentives, for example quotas to fulfil or a tax to be paid on emissions. In the second, the market use of the methane emissions, which of course depends on general economic circumstances (price of natural gas and energy in general) as well as local circumstances (e.g. a nearby gas pipeline or energy-consuming industry) may be enough to justify investing resources in the capture, transportation and processing needed to re-use the product on the market. Obviously, in this case, the incentive that a regulation or tax can provide adds to the project's profitability. For instance, in Europe today, in the context of rapidly rising oil and natural gas prices, re-using landfill methane for thermal or electric purposes is generally enough to make the project profitable. It is clear that this would not be the case with, for example, more CH_4-sober cropping or stock farming practices, or landfill or mine methane emission flaring. In these cases, only incentives of various natures are likely to generate the necessary investments and practices. Thus, when one analyses the various sectors and technologies that intervene in reducing methane emissions, one can classify them in two principal categories: those that allow a material good to be produced and used, and those that arise above all from a will to reduce methane emissions.

Those that allow the production and use of a material good (an energy product) for which there is a market. These find actors (producers and consumers) that ensure the desired reduction in methane emissions, possibly but not systematically with the help of regulatory or fiscal incentives.

This category includes:

- The capture and re-use of landfill methane in Europe, either by post-filtering injection of the gas into natural gas networks, or by the processing and distribution of electricity and heat.

- Farm methane, which is highly developed in Northern European countries (and in Asian countries such as Vietnam), for which subsidies applicable to renewable energies (including biogas) ensure the profitability of combined heat and power plants that use the biogas produced both by stock farming waste (manure and slurry) and agricultural residue from a group of farms. In Germany, for example, several thousand such installations operate.[22] It should be noted that these installations were not originally intended to reduce methane emissions in order to fight climate change, but rather to convert agricultural waste into energy. This can lead to the transformation into biogas of waste that would otherwise have produced little or none. In the context of fighting CH_4 emissions, one must therefore be very attentive to sealing the methanation system to prevent any leaks that would lessen the interest of this additional biogas production.

- Capturing methane from coal mines. In coal mines, there are three primary sources of methane: that drained before mining

22. www.biogaz.atee.fr

is begun, which is 65% to 90% CH_4; that contained in the mine's ventilation air, the concentration of which is very low (0.1% to 1%); and finally that drained from areas of the mine that have already been mined, which is 30% to 95% CH_4. Drained gas with a CH_4 content of more than 30% can be used directly to produce electricity, or injected into gas networks after it is purified. In the United States, for example, 27% of the methane drained from mines is re-used in this way.

- The methane from oil wells, which is re-used whenever local use is possible (producing electricity for auxiliary use in the oil field or direct supply to a nearby industry).

b) Those that arise above all from a will to reduce methane emissions, and for which waste-to-energy is not economically feasible or serves no purpose (reduction at the source).

These notably include:

- The mine ventilation gas that generally accounts for more than 60% of total gas emitted by a mine over its lifetime. Until ventilation gas recycling procedures have received industrial confirmation, the current elimination procedures rely on the thermal or catalytic oxidation of very low concentrations of methane.[23]

The gas flared in the field in the oil sector, when the conditions for re-use are not met:

- Gas leaks in natural gas transportation, storage and distribution systems the reduction of which is not justified by commercial gains or safety concerns for natural gas distributors.

- Agricultural practices in rice cropping or stock farming that emit little methane and that do not result in improved yields or better productivity.

In all these cases, regulatory or fiscal incentives (quotas, taxes, subsidies) are indispensable to trigger investments or generate practices that lead to the desired reduction in emissions. This situation is analogous to that of energy savings that would benefit the society as a whole but from which the investors would not profit directly by a drop in their operating expenses.

This rapid overview reveals a very wide diversity of situations in function of the sectors and technologies involved in reducing methane emissions. To be efficient, planning actions and incentive policies must take into careful account these specificities.

6.2 Methane and the Carbon Market

The preceding considerations and those in regard to the under-estimation of methane set forth in chapter 2 raise questions as to the relevance and limitations of choosing non-differentiated targets for the reduction of various greenhouse gas emissions and a single carbon market through the definition of an equivalence coefficient for the various GHGs. This is all the more true as the lifetime of emission reduction measures has very different consequences for methane and CO_2.

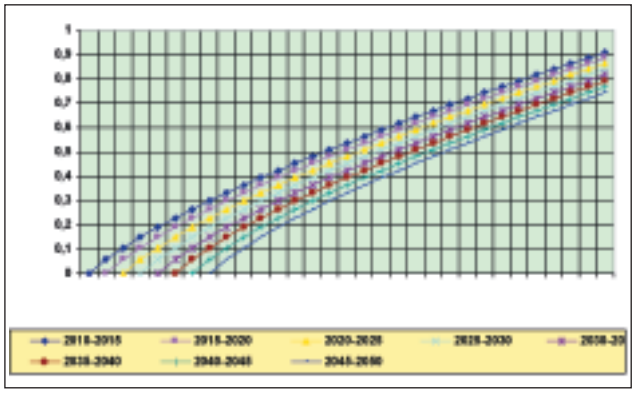
The analysis we have undertaken in Appendix 1 provides figures to partially answer this question of the lifetime of CH_4 and CO_2 emission reduction measures. A simple example illustrates this. Let us imagine a measure to reduce CO_2 emissions by 1 kg per year rolled out in 2010 with a lifetime of 40 years. Figure 15 shows the evolution of integrated forcing for savings of 1 kg of CO_2 in a succession of 5-year periods over 40 years.

23. Ibid. footnote 9.

This figure shows that the measure's cumulated radiative forcing grows slowly over time because, in 2160, it will still be far from having reached its maximum and will still continue to grow significantly. It is very different with methane, as Figures 17 and 18 show. The initial slope of the curves is much steeper: the cumulated forcing of the 40-year measure rises very quickly. It reaches its asymptote as early as 2070 or 2080, with more than 99% of its value at 500 years.

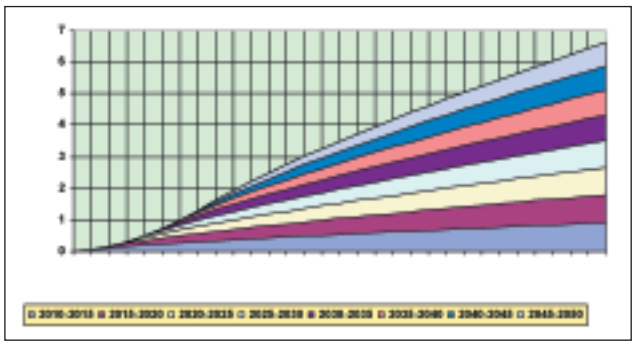
The influence of the lifetime of an emission reduction measure is therefore very different for carbon dioxide and methane. Table 13 illustrates the importance of this statement.

Figure 15. Avoided Radiative Forcing for Each Successive 5-Year Period of One Measure Suppressing One Mass Unit of CO_2 Over 40 Years



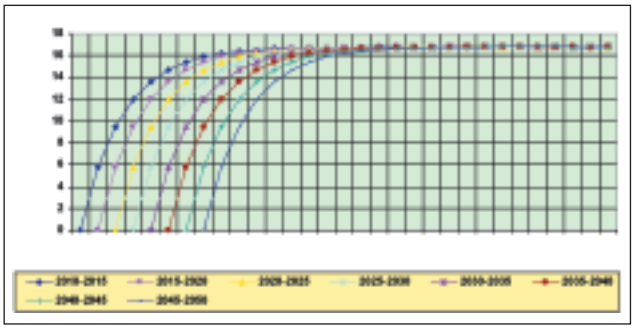
Source: Authors' calculations.

Figure 16. Shows the changes in forcing generated by the cumulation of these measures over 10, 15, 20, etc. years.



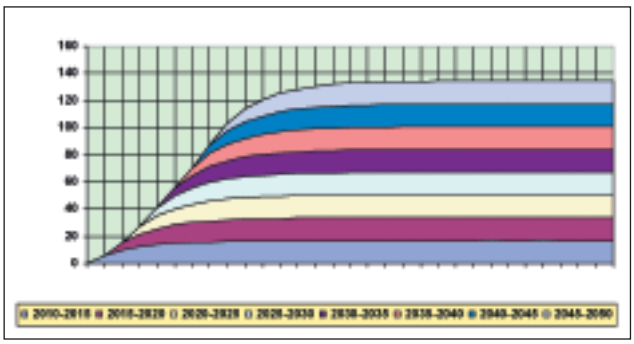
Source: Authors' calculations.

Figure 17. Avoided Forcing for Each Successive 5-Year Period of One Measure Suppressing One Mass Unit of CH4 Over 40 Years



Source: Authors' calculations.

Figure 18. Avoided Radiative Forcing for One Measure with a Lifetime of 40 Years Suppressing One Mass Unit of CH_4 in 2010



Source: Authors' calculations.

Table 13. Avoided Radiative Forcing According to the Lifetime of the Emission or the Avoided Emission

This table's horizontal scale represents the periods of time over which we wish to evaluate the integrated consequences of one emission of CH_4 or CO_2; the vertical scale, the lifetime of the emission or the emission reduction from the start of the period.

GHG	Lifetime of the Emission or the Avoided Emission	Time Horizon (year)									
CH_4		10	20	30	40	50	60	70	80	90	100
	10 years	5.5	8.6	9.5	9.8	9.9	10.0	10.0	10.0	10.0	10.0
	20 years	5.5	12.5	17.1	18.8	19.5	19.8	19.9	20.0	20.0	20.0
	30 years	5.5	12.5	20.5	26.1	28.3	29.3	29.7	29.9	29.9	30.0
	40 years	5.5	12.5	20.5	29.3	35.4	38.0	39.2	39.6	39.8	39.9
	50 years	5.5	12.5	20.5	29.3	38.6	45.1	47.9	49.1	49.6	49.8
	60 years	5.5	12.5	20.5	29.3	38.6	48.2	54.9	57.8	59.0	59.6
	permanent	5.5	12.5	20.5	29.3	38.6	48.2	58.0	67.9	77.9	87.9
CO_2		10	20	30	40	50	60	70	80	90	100
	10 years	5.2	7.8	8.6	9.0	9.2	9.4	9.4	9.5	9.6	9.6
	20 years	5.2	10.7	14.2	15.9	16.8	17.4	17.8	18.0	18.3	18.5
	30 years	5.2	10.7	16.3	20.3	22.6	23.9	24.9	25.6	26.1	26.5
	40 years	5.2	10.7	16.3	22.0	26.3	29.0	30.7	32.0	32.9	33.7
	50 years	5.2	10.7	16.3	22.0	27.7	32.2	35.2	37.3	38.8	40.0
	60 years	5.2	10.7	16.3	22.0	27.7	33.4	38.1	41.3	43.6	45.4
	permanent	5.2	10.7	16.3	22.0	27.7	33.4	39.1	44.8	50.5	56.2

Source: Authors' calculations.

Thus, Table 13 reads as follows: Over a period of 100 years, the effect on the climate generated by reducing emissions by 1 kg of CH_4 over the first 30 years is equivalent to the effect of reducing emissions by 30 kg of CH_4 the first year. However, over the same 100-year period, the effect generated by a permanent emission reduction of 1 kg of CH_4 is equivalent to the effect of an emission reduction of only 87.9 kg of CH_4 the first year (instead of the 100 kg one could have imagined). Similarly, over a period of 100 years, the effect generated by reducing emissions by 1 kg of CO_2 over the first 30 years is equivalent to the effect of reducing emissions by 26.5 kg of CO_2 the first year; and the effect generated by a permanent emission reduction of 1 kg of CO_2 is equivalent to the effect of an emission reduction of only 53.5 kg of CO_2 the first year (instead of the 100 kg one could have imagined).

Consequently, there are two important results:

- the overall effect on the climate of an emission reduction depends on its temporal profile; and
- the variation over time of this effect is specific to each gas. For CH_4, the differences in effect between a single emission at the start of the period or spread over several years or decades are small. This is not the case for CO_2, for which differences are much greater.

The physics of the phenomena therefore lead to two decisive observations:

a) The decision to express multi-gas emissions reduction targets in tonnes of CO_2 equivalent masks the fact that strategies of action that emphasise different GHGs have different impacts on the climate even though they would be viewed as equivalent in light of their results in tonnes of CO_2 equivalent. This obviously calls into question the use of this concept.

b) The postulate that it would be legitimate to establish, via a common unit of measurement (such as the tonne of CO_2 equivalent), equivalences among very diverse (in terms of sector or geography) actions is invalidated as soon

as one truly takes into account the lifetime of emission reduction investments and, moreover, the specific evolution of each gas.

Under these conditions, one can clearly see the distortions that risk being generated by the establishment of a single carbon market supposed to optimise all actions on the various greenhouse gases regardless of the time horizon in question. We could envisage correcting the equivalence coefficient for CH_4 and CO_2 and in this way adapting it to the shorter-term preoccupations of the international community. However, if we increase this coefficient by very much (by a factor of 3 or more, for example, at the 2040 time horizon), we run the risk of seeing the market turn totally away from CO_2 actions in favour of CH_4 actions (which suddenly become much more profitable) and thereby falling dangerously behind when it comes to the CO_2 actions that are vital to ensuring the long term.[24]

24. Not counting the risk of the collapse of the carbon exchange that could be brought about by the adoption of a coefficient that is much more favourable to CH_4 than to CO_2 than the present coefficient.

7. Conclusions for Action

7.1 It Is Vital and Urgent that We Attend Seriously to CH_4

The IPCC's most recent studies show that climate change is an issue for a much sooner future than decision makers generally imagine. Indeed, according to these studies, it is not enough to maintain the concentration of all greenhouse gases below a certain threshold (approximately 400 to 450 ppm) in the next century; we must also do so by taking a path that does not, during this century, lead to irreversible climate changes that make the final target unattainable. It is therefore vital to act in the short term to redress the current, still very rapid, growth in GHG emissions (3% per year) and thereby keep their concentration below 500 ppm in the coming decades. In this context, using a 100-year equivalence of the effects of CH_4 compared to CO_2 (coefficient 21) leads to an under-estimation of the effects of CH_4 during the current century by a factor of 4 in the short term (20 years) and a factor of 2 at the end of the century. Today, most policy makers, relying on the 100-year equivalence (thus valid for the effects in 2108 of a CH_4 emission in 2008[25]), focus all their attention on carbon dioxide emission reductions and largely ignore methane and nitrous oxide, neither of which are the subject of any large-scale international plans). This is especially worrying for methane whose global warming potential increases very quickly when the observation period is shortened.

7.2 The Consequences of a Global Methane Emission Reduction Policy in the Coming Decades Are Considerable

Comparing actions strategies that focus on only CO_2 or on both methane and CO_2 shows that the latter are far from marginal in relation to those that can be taken on CO_2 alone. If two global emission reduction programmes are undertaken at the same pace starting now, reaching -40% for CO_2 and -30% for CH_4 in 2030, the effectiveness of the CH_4 programme will be half that of the CO_2 programme in 2030, will still be 44% in 2040, and 39% in 2050.

7.3 There Is Considerable Potential to Reduce Methane Emissions in the Short and Medium Term (by Approximately 30% by 2030) in both Industrial and Emerging Countries Equally

Current world methane emissions—approximately 360 Mtonnes and fairly evenly distributed around the world—come from agriculture and stock farming (40%), then energy systems (coal, gas and oil, 33%), and household waste landfills (23%). A first analysis estimates the potential to cut these emissions by approximately 30% in 20 years' time: approximately 50 Mtonnes from all energy systems, 40 to 45 Mtonnes from landfills, and 10 to 20 Mtonnes from stock farming and agriculture, for a total of 100 to 115 Mtonnes.

25. This is true when comparing the effects of two single emissions. If one reasons in terms of permanently avoided emissions, the equivalence is pushed back to approximately 250 years.

7.4 This Potential Can Be Realised Quickly at Reasonable Cost Without Endangering Development

In the current context of fossil fuel prices, a significant proportion of this emission reduction potential (household waste and a large share of leaks from energy systems) can be cost-effectively harnessed simply by recovering the methane for energy production purposes. For the remaining potential, regulatory or fiscal incentives are crucial.

In "industrial" countries where the constraints are considerable as GHG emissions must be divided by 4 by 2050, large-scale CH_4 action would make it possible to loosen the very strong time constraint on CO_2 reductions, a large share of which require structural measures: insulating old housing, new rail transport infrastructure, densification of urbanism, etc., the implementation calendar for which covers several decades. Most of the potential methane emission reduction measures can, on the contrary, be taken over a period of approximately ten years at generally modest cost. This is the case, in particular, for methanation or methane capture actions on waste or effluents.

In developing and emerging countries, even if the indispensable energy efficiency and energy diversification efforts are made, these countries' necessary economic growth will inevitably lead, at least temporarily, to a rise in CO_2 emissions, primarily linked to the energy system. However, the linkage of economic growth and CH_4 emissions in these countries is far from inevitable. Seeking to massively and rapidly decouple methane emissions from GDP growth should therefore provide a major opportunity for emerging countries to put themselves on a path towards controlling increases in their GHG emissions in the medium term (20 to 60 years). This is particularly true since the corresponding investments can often be recouped by providing a new energy service (farm biogas, for example) or switching away from fossil fuels.

7.5 Define Suitable Programmes and Tools

The definition of short- and medium-term programmes of action in both industrial and developing countries runs up, first, against the imprecision or even lack of sector-based data on current methane emissions. Most of the data published by the various countries (and in particular non-Annex I countries) date from 1994, or even 1990.

It is therefore urgent that a reliable database of emissions be established country by country and sector by sector based on the physical quantities of methane emitted and not, as is seen too often (when the data exist), based on a CO_2 equivalence at 100 years, the limiting nature of which we have seen. This precise database is crucial for raising awareness of the sectoral stakes among policy makers from all countries involved in fighting climate change and monitoring the emission reduction programmes to be undertaken in the coming decade. Simultaneously, it is appropriate to **begin defining and negotiating priority programmes of action, country by country,** based on a first analysis of the largest and most accessible sectors in

terms of potential. Obviously, this means informing public leaders and socio-economic actors (generally little concerned with methane emissions even when they are concerned about the climate) on and raising their awareness of the stakes of and consequences one can expect from these programmes. This information deals equally with the scope and nature of the emission reduction potential in each sector and the technologies to utilise as well as the economic conditions of their use.

Finally, it seems to us indispensable to frame this approach by **renewing the reflections on the very objectives of the climate negotiations.** Indeed, it clearly emerges from our analysis that setting multi-gas emission reduction targets translated into a single target reduction in t CO_2 eq has considerable undesirable effects since:

- if one insists too much on reducing CH_4 to the detriment of CO_2 reductions because of the short and medium term, there is a risk of not attaining the long-term GHG concentration stabilisation targets; but
- if one neglects reducing CH_4 emissions, one increases the risk of seeing irreversible changes that endanger the climate.

In these conditions, it seems important to define GHG reduction targets gas by gas, at the very least for those gases, like methane, whose global warming power varies very quickly over time. Similarly, it does not seem relevant to ensure the permanence of a carbon market that indiscriminately encompasses, as is the case today, greenhouse gases that have such different temporal consequences on the climate as do CH_4 and CO_2.

Appendix 1. Global Warming: The Significance of Methane

Benjamin DESSUS, Bernard LAPONCHE, Hervé LE TREUT (February 2008)

1. Climate change targets

At its meeting on 30 October 2007, the EU Environment Council adopted the recommendation to avoid global warming of more than 2°C and recognised that *"stabilisation of the concentration of greenhouse gases in the atmosphere [...] to about 450 ppmv CO_2 eq"* is required. The Environment Council underlined that *"this will require global greenhouse gas emissions to peak within the next 10 to 15 years, followed by substantial global emission reductions to at least 50% below 1990 levels by 2050".* Finally, the Council stresses that achieving this target, *"would require the group of developed countries collectively to reduce their emissions in a range of 25-40 % below 1990 levels by 2020",* noting that *"the EU's proposal for emission reduction commitments of the group of developed countries is consistent with this level of effort".*

In this text, the "concentration of 450 ppmv of CO_2 equivalent" means the simultaneous presence of a set of greenhouse gases (CO_2, CH_4, N_2O, etc) in the atmosphere in varying concentrations which do not have the same impact on global warming. However, their impact can be estimated as being equivalent to what the 450 ppmv concentration of CO_2 alone would have caused. There are several gases whose emissions are responsible for enhancing the greenhouse effect: CO_2, CH_4, N_2O, CFC, etc. Each one of these "greenhouse gases" (GHGs) has its own particular properties in terms of infrared absorption and atmospheric lifetime after being emitted. In their simulation models, the experts who study climate change use data on emissions and concentrations of each of these GHGs in different scenarios in order to anticipate climate change.

The recommendation for stabilisation at "450 ppmv CO_2 equivalent" is thus based on results of scenarios that anticipate emission reductions of the different GHGs needed at different time horizons in order to limit global warming to around 2°C at the beginning of the next century: for example, a factor two reduction of CO_2 emissions, a 30% reduction of CH_4 and N_2O in 2050 compared to 2000 levels. It is obvious that if this simultaneous effort to reduce emissions of the different gases is not made, the CO_2 reduction envisaged will not be enough alone to reach the 450 ppmv CO_2 equivalent target and thus to limit global warming to 2°C.

However, in the same conclusions of the EU Environment Council of 30 October 2007 on reduction efforts needed, only CO_2 emission reduction efforts are cited. Non CO_2 GHGs (CH_4, N_2O, etc) are not specifically mentioned at all. Similarly, as part of the French national consultation to reform environmental policy *(Grenelle de l'Environnement),* conducted in 2007, after it was declared that the EU recommendations would be complied with, all the measures proposed focus on CO_2 emission reductions. The final document does not once mention CH_4.

2. Taking methane emissions into account and the "global warming potential"

This lack of apparent interest for the other GHGs is probably linked to the use of highly simplified tools for assessing their role in reduction policies. Calculating emissions of the different GHGs in “tons of CO_2 equivalent”, which rapidly became the norm with policy makers, has a very specific meaning but it is not suitable for all contexts and may, in certain cases, lead to an optical effect of distorting the issue at stake. In order to simplify the overall assessment of the impact of emissions of these different GHGs on climate change, it was decided to use rules of equivalence to make it possible to take into account emissions of non CO_2 GHGs within one single unit: the ton of CO_2 equivalent (t CO_2 eq). It is commonly defined on the basis of the relative impact of each gas on global warming compared to that of CO_2, calculated over a determined period of time which follows the emission of each GHG, for example 100 years. This climate impact is determined as the cumulative radiative forcing linked to a given GHG over the period under consideration.

The convenience of using the t CO_2 eq as a single unit has very quickly led to its widespread use, whether it be for past emissions that have been observed or future emissions anticipated (particularly in climate policy targets) as cumulated emissions over a specific (past or future) period. In most documents setting out climate change mitigation programmes, it appears as if there were only one GHG involved, the “CO_2 equivalent” whose emissions need to be reduced.

3. The dangers of using GWP too directly

Whereas the First Conference of the Parties (COP 1 1995) merely stated that *"Parties **may**[26] use global warming potentials to reflect their inventories and projections in carbon-dioxide-equivalent terms. In such cases, the 100-year time-horizon values provided by the Intergovernmental Panel on Climate Change in its 1994 Special Report should be used",* the use of GWPs over a 100-year period very quickly became the norm. The pulse emission of 1 t of CH_4 in 2000 is counted as 21 t CO_2 eq[27] on the basis of the cumulative effects respectively of CH_4 and CO_2 between 2000 and 2100, and the emission of 1 t of CH_4 in 2020 for example is counted as 21 t CO_2 eq on the basis of the cumulative effects respectively of CH_4 and CO_2 between 2020 and 2120: the impacts of a CH_4 emission compared to those of an emission of the same volume of CO_2 are each year put back 100 years.

Adopting such a rule has significant consequences on the relative assessment of the role of the different GHGs. While the use of the concept of CO_2 equivalent, as previously shown, does not present any ambiguity to estimate concentrations, using it to estimate emissions necessarily implies that a reference is made to an integration period from when the emission is made[28].

As the atmospheric lifetime of CH_4 is short compared to that of CO_2, the GWP of CH_4 varies considerably depending on the period of time chosen.

With the rule of the equivalence coefficient being 21 (GWP over a 100-year period following the date of emission), it is therefore impossible to estimate the impact at a given time horizon (2020, 2050, 2100) of a CH_4 emission. To make this estimate, it is necessary to take into account the difference between the year of emission and the year of the time horizon since the equivalence coefficient (the GWP) rapidly varies depending on the time period chosen to measure the respective impacts of CO_2 and CH_4 on global warming.

26. Authors' emphasis.
27. The coefficient 21 was adopted in particular by the Kyoto Protocol on the basis of the IPCC publications in 1995 and has been retained ever since.
28. The CO2 equivalence for concentrations and the CO2 equivalence for emissions are two different concepts.

Furthermore, it is vital to bear in mind the fact that the GWP concept applies to climate impacts of a pulse emission at a given point in time. To apply it without caution to measures which continue over time in order to estimate the impact at a given time horizon may thus lead to serious errors of assessment.

4. Calculating the GWP

The GWP calculation for CH_4 at different time horizons was made on the basis of the most recent IPCC indications[29-30], by a three step method:

a) by reconstituting the CO_2 and CH_4 decline curves in the period 0-500 years;
b) from there, by calculating the AGWPs of CO_2 and CH_4 using values of the radiative efficiency of these two GHGs provided by the IPCC[31] ;
c) then calculating the GWP of CH_4 as the ratio of the AGWP for CH_4 to the AGWP for CO_2, for the same unit of mass, for example 1 kg.

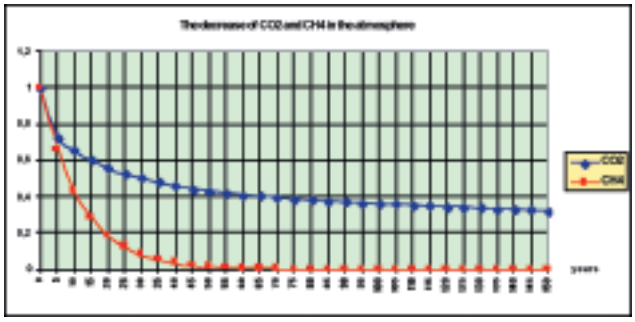
The decrease of CO_2 and CH_4 in the atmosphere

The decline curve for CH_4 emitted in the atmosphere is the exponential e-t/12.

The decline curve of CO_2 emitted in the atmosphere is the sum of a constant and three exponential curves, one of which corresponds to a very rapid decline (less than two years' lifetime).

The two decline curves are presented in figure 19, for an emission of 1 unit of mass at year 0.

Figure 19. The decrease of CO_2 and CH_4 in the atmosphere

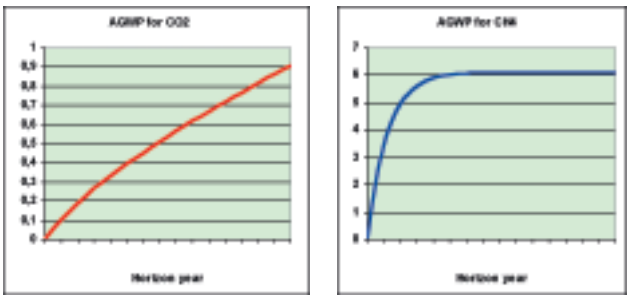


Source: Authors' calculations, IPCC 2007.

The AGWP of CO_2 and CH_4

For the calculation of the AGWP for CH_4, we take into account the indirect effect on global warming caused by the decline of CH_4 in the atmosphere, on the basis of the 2007 IPCC report. The values of AGWP presented in figure 20 are given for 1 ppm[32].

Figure 20. The AGWP of CO_2 and CH_4

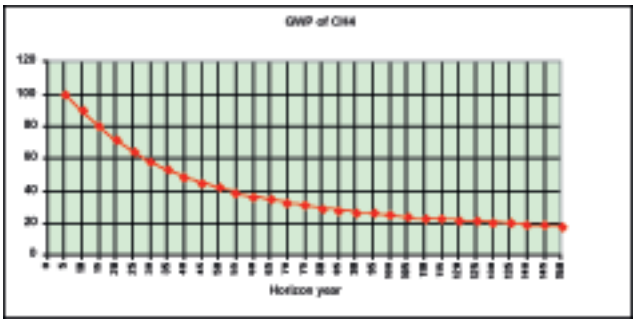


Source: Authors' calculations.

The AGWP of CO_2 and CH_4

The GWP for CH_4 is calculated as the ratio of the AGWP of CH4 to the AGWP of CO_2, for an emission of 1 kg of each gas at year 0[33].

Figure 21. The GWP of CH_4



29. Reference: IPCC " Climate Change 2007 : Working Group I: The Scientific Basis".
30. ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf
31. For the same unit of mass present in the atmosphere, the radiative efficiency of CH_4 is equal to 73 times that of CO_2.
32. The AGWPs for a 1 kg emission have also been calculated for each gas.
34. The value of the GWP for CH_4 and for an emission of 1 kg of both gases is equal to the ratio of the AGWPs per ppm (figure 20) multiplied by 44/16.

The GWP values thus obtained are equal to the values provided by the IPCC for 20, 100 and 500 years (respectively 72, 25 and 7.6) . They are presented in Table 14 and Figure 21.

Table 14: The value of the GWP of CH_4 depending on the time horizon (year of emission : 0)

Year	5	10	15	20	25	30	35	40	45	50
PRG	101	90	80	72	64	58	53	49	45	42
Year	55	60	65	70	75	80	85	90	95	100
PRG	39	37	35	33	31	30	28	27	26	25
Year	105	110	115	120	125	130	135	140	145	150
PRG	24	23	23	22	21	21	20	19	19	18

Source: Authors' calculations.

This shows that the effect on global warming due to the emission of 1 kg of CH_4 in year 0 is the same, over a period of 100 years, as the effect of the emission of 25 kg of CO_2 in year 0; over a period of 20 years, of the emission of 72 kg of CO_2 in year 0; and over a period of 50 years of the emission of 42 kg of CO_2 in year 0.

5. Comparison of two measures to reduce CH_4 and CO_2 emissions

The example given below shows the order of magnitude of the assessment errors that are likely to be made by using "the 100 years equivalence".

We consider two measures to reduce CH_4 and CO_2 emissions:

a) firstly, in the year 0, putting a permanent end to the source of an annual emission of 1 kg of CH_4 (which would continue if this measure were not implemented), i.e. 21 kg CO_2 eq according to current methodology). We call this "CH_4 measure": from year 1, the CH_4 emission avoided is thus 1 kg each year.

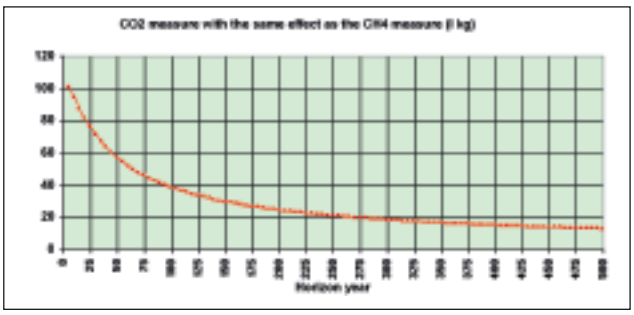
b) secondly, in the same year 0, putting a permanent end to the source of an annual emission of 1 kg of CO_2 (which would be permanent if this measure were not implemented). We call this "CO_2 measure": from year 1, the CO_2 emission avoided is thus 1 kg each year.

We calculate the compared impacts on global warming of each measure at different time horizons starting from the horizon year 1.

The respective cumulative effects of each emission avoided during the whole of the period between the year in which the measure was implemented and the horizon year is obtained by adding together the "absolute" GWPs of CH_4 and CO_2.

The ratio of the cumulative effects allows us to draw a comparison between a permanent CH_4 emission reduction measure and a permanent CO_2 emission reduction measure. Figure 22 shows the results obtained, for each horizon year between 0 and 500 years, in five-year stages, for putting a permanent end to an emission of 1 kg of CH_4 (21 kg CO_2 eq according to current methodology) in the year 0.

Figure 22. CO_2 measures with the same effect as the CH_4 measure (1 kg)



Source: Author's calculations.

Table 15 indicates for the significant horizon years the values in kg CO_2 of permanently avoided CO_2 emissions in the year 0 which has the same impact on global warming at the time horizon as putting a permanent end to the emission of 1 kg of CH_4 in the year 0.

Table 15: Value of the CO_2 measure with the same effect as the CH_4 measure at different time horizons

Horizon year	20	50	100	250	500
kg CO_2	81	57	39	21	13

Source: Authors' calculations.

At 20 and 50 year time horizons, the underestimated impacts of using the GWP of 21 is thus highly significant (respectively a factor of 3.9 and 2.7). It is still a factor of 1.9 at a horizon of 100 years and does not reach the value of 1 until 250 years have elapsed.

6. Comparison of emission reduction policies

The same calculation may be made for different years in which the measure to put an end to a CH_4 and a CO_2 emission is implemented. These years may be different for each GHG and be spread over different periods. It is also possible to examine stopping emissions permanently or over a limited period of time.

For each year or period that the CH_4 measure is implemented and for each horizon year, comparing the impacts results in a quantity of CO_2 whose emission that stopped permanently in the same year or in the same period the measure was implemented (CO_2 measure) would have the same effect on global warming in the same horizon year as the CH_4 measure to permanently reduce the emission of 1 kg CH_4 for this period in which the measure was implemented.

This method thus enables comparisons to be drawn between CH_4 and CO_2 emission reduction policies, for reductions that are permanent or limited in time.

7. What are the conclusions of this demonstration?

Firstly, it is important to be fully aware that using the "100-year GWP" to measure non CO_2 GHG emissions is not well suited to the case of permanent or long lifetime measures whose effectiveness is to be assessed at a given time horizon. In this context, it contributes to significantly playing down the importance of reducing emissions of GHGs with short atmospheric lifetimes. Thus, for example, methane which is not emitted over the period 2020-2100 as a result of a landfill site being closed in 2020 will have an impact (as opposed to if the site remained in operation) that would be far greater towards 2100 compared to a CO_2 emission source that has also been stopped permanently and whose climate impact is measured in an equivalent manner.

Using the GWP is only appropriate if applied year after year to time horizons considered to be of concern or decisive by climate studies, thus in particular 2050, 2100 and 2150. This is all the more significant as climate experts' current concerns lead them not only to advocate long-term stabilisation of GHG concentrations but also to avoid as far as possible intermediate exceedances of these concentrations over the coming century.

Finally, it is noted that CH_4 prevention policies implemented in the short term may continue to have a long-term impact greater than merely taking into account the current GWP would imply. To more or less ignore the impact of CH_4 as it is unsuitable for accounting purposes affects the exclusive character of the link that may exist between the issue of GHGs and that of energy. Furthermore, if the increase in atmospheric concentrations of CH_4 which was significant following the onset of the industrial revolution, has slowed down in the last few years for reasons that are still being debated, a renewed sharp increase in the event of the Arctic region melting, for example, remains quite possible.

It is thus important, now that the most recent IPCC report points to the consequences of climate change in the medium term, that GHG emission reduction policies be defined individually for each GHG: both CH_4 and N_2O, on the basis of their real emissions, consistent with the scenarios used by climate experts and depending on the concentration levels they recommend be achieved at given time horizons. Purely economic and financial considerations linked to the emissions trading markets must not mask the importance of robust policies aimed at non CO_2 GHGs. Specifically, in addition to the vital CO_2 emissions reduction effort, greater attention must be paid to short-term reductions of CH_4 emissions whose impacts are significant at a time horizon of a few decades. Climate experts and policy makers should make the most of the two-year negotiating period on the post 2012 regime, officially launched at the recent Bali Climate Conference, to give thought to this issue.

Appendix 2. Comparison of Two Emission Reduction Programmes for CH_4 and CO_2

(B. Dessus - B. Laponche – March 2008)

Comparison of Cumulated Avoided Radiative Forcing at Different Time Horizons for Two Permanent Emission Reduction Programmes for CO_2 and CH_4 over the 2010-2050 Period

1. Two Emission Reduction Programmes for CH_4 and CO_2

We compare two permanent emission reduction programmes for CH_4 and CO_2 over the 2010-2050 period:

- *CH_4 Programme:* Each year, starting in 2010 and until 2050, an action is taken that permanently (here, at least until 2050) eliminates one emission of 1 t of CH_4.
- *CO_2 Programme:* Each year, starting in 2010 and until 2050, an action is taken that permanently (here, at least until 2050) eliminates one emission of 21 t of CO_2.

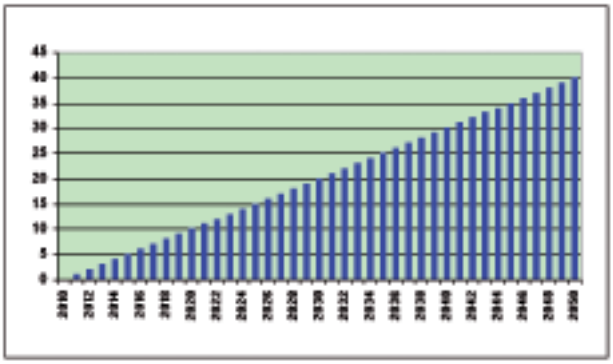
The emissions avoided in each of the two programmes are indicated in Figure 23.

Comments:

For example, in 2020, the avoided emission is 10 t of CH_4 in the CH_4 programme (or 210 t of CO_2 in the CO_2 programme) because of the cumulation of emissions avoided due to the emission reduction actions conducted each year from 2010 to 2020.

With the current greenhouse gas emission accounting, these two programmes are seen as having equivalent effects on global warming because each represents the permanent elimination of one emission of 21 tonnes of CO_2 equivalent (t CO_2 eq) each year over the period in question.

Figure 23. Emissions Avoided Each Year in Each Programme



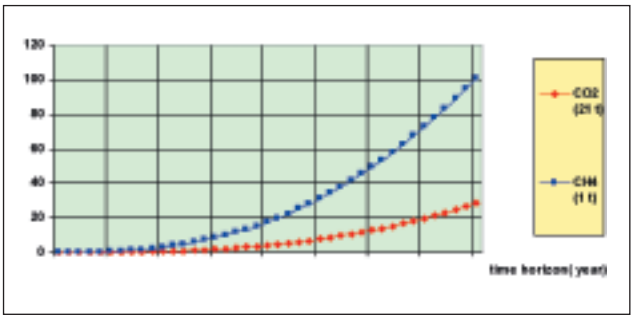
Source: Authors' calculations.

2. Integrated and Cumulated Avoided Radiative Forcing

For each of the programmes, we have calculated[34] the integrated[35] and cumulated[36] radiative forcing avoided due to each programme at the time horizons of each year between 2010 and 2050.

Figure 24 shows the respective radiative forcing values for the two programmes.

Figure 24. Integrated and Cumulated Radiative Forcing Avoided



Source: Authors' calculations.

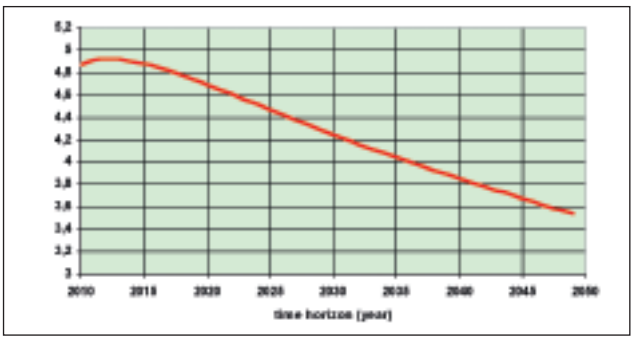
Comments:

For example, the cumulated radiative forcing avoided in 2030 due to each of the programmes applied from 2010 to 2030 is respectively 4.1x10-^{8} Watt-year/m^{2} for the CO_2 programme and 17.4x10-^{8} Watt-year/m^{2} for the CH_4 programme. Similarly, the cumulated radiative forcing avoided in 2050 due to each of the programmes applied from 2010 to 2050 is respectively 28.4x10-^{8} Watt-year/m^{2} for the CO_2 programme and 100.5x10-^{8} Watt-year/m^{2} for the CH_4 programme

3. Integrated and Cumulated Avoided Radiative Forcing Ratio for Each of the Programmes at Different Time Horizons

The radiative forcing ratio of each programme, integrated and cumulated for each time horizon, is presented in Figure 25.

Figure 25. Ratio of Integrated and Cumulated Radiative Forcing Avoided



Source: Authors' calculations.

Comments:

If both programmes are conducted over the 2010-2020 period, the ratio in 2020 is 4.7, 4.3 in 2030, 3.9 in 2040, and 3.5 in 2050.

If we believe that the time horizon between 2030 and 2050 is crucial for climate change, we must keep in mind that the importance of one additional permanent avoided emission each year of 1 t of CH_4 is not equivalent to that of one additional avoided emission each year of 21 t of CO_2, but to that of one additional avoided emission each year of approximately 80 t of CO_2 over the same period.

34. See Appendix 1.
35. "Integrated Avoided Radiative Forcing": integrated radiative forcing avoided from the year of the action to the horizon year.
36. "Cumulated Avoided Radiative Forcing": integrated avoided radiative forcing for each year of action cumulated for all years of action from 2010 to the horizon year.

Glossary

- **Annex I Countries**

Annex I of the Framework Convention on Climate Change lists the countries who were members of the OECD in 1992, eleven countries undergoing the process of transition to a market economy, and the European Economic Community. The parties to the Convention listed in Annex I are committed to adopting national policies and taking measures to mitigate climate change.

- **Carbon Cycle**

The term used to describe the exchange of carbon (in various forms, e.g., as carbon dioxide) between the atmosphere, ocean, terrestrial biosphere and geological deposits.

- **Climate**

Climate generally refers to "average weather." More specifically it is defined as the statistical description of weather in terms of the mean and variability of relevant quantities over a period of time of several decades (three decades in principle, according to the definition given by the World Meteorological Organisation [WMO]). These relevant quantities are most often surface variables—temperature, precipitation, and wind, for example—but "climate" in the broader sense is the state of the climate system.

- **Climate Change**

Climate Change (UNFCCC usage)
Changes of climate which are attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Climate Change (IPCC usage)
Climate change as referred to in the observational record of climate occurs because of internal changes within the climate system or in the interaction between its components, or because of changes in external forcing either for natural reasons or because of human activities. It is generally not possible to establish the causes clearly. Projections of future climate change reported by IPCC generally consider only the influence on climate of anthropogenic increases in greenhouse gases and other human-related factors.

- **Climate Sensitivity**

In IPCC reports, this expression usually refers to long-term (equilibrium) changes in global mean surface temperature following a doubling of atmospheric CO_2 (or CO_2 equivalent) concentration. More generally, it refers to the equilibrium change in surface air temperature following a unit change in radiative forcing (°C/W/m^2).

- **CO_2 Equivalent**

- *For GHG concentrations:*
The concentration of CO_2 that would cause the same amount of radiative forcing as the given mixture of CO_2 and other greenhouse gases. The units of measurement used are the tonne CO_2 equivalent (t CO_2 eq) or the part per million in volume (ppmv) of CO_2 eq. (see "ppm").

- *For GHG emissions:*
An emission of one tonne of a greenhouse gas other than CO_2 is conventionally expressed in "tonnes of CO_2 equivalent" (t CO_2 eq) using the "global warming potential" over a 100-year period. The conventional values used for 100-year GWPs were set based on the IPCC's work in 1997 (Kyoto Protocol).
The t CO_2 eq for concentrations and the t CO_2 eq for emissions refer to two different concepts.

- **Emission Permit**

A non-transferable or tradable allocation of entitlements by a government to an individual firm to emit a specified amount of a substance.

- **Global Warming**

Global warming is the increase in the average global temperature of the Earth's oceans and atmosphere over several years. In its most common accepted meaning, this term is applied to climate change (see the definition of climate change).

- **Global Warming Potential (GWP)**

GWP is an index of comparison associated with a given greenhouse gas (GHG) that measures its marginal contribution to global warming compared to that of carbon dioxide (CO_2) over a specific given period of time. In other words, the GWP of a gas is the difference between the effects caused by the liberation at the start of the period of a given mass of the gas in question and those caused by the same mass of carbon dioxide (CO_2). By definition, the GWP of CO_2 always equals 1. The respective effects are deliberately calculated over the chosen period; residual effects after this period are ignored. This period (or at least its duration) must be mentioned when the GWP is given as the GWP value is meaningless without this information.

The GWP of a given GHG at time horizon TH and for year 0 emissions is the ratio of the integer from 0 to TH of the function of the decrease over time of the given GHG multiplied by the radiative efficiency of the gas to the integer from 0 to TH of the function of the decrease of CO_2 over the same period multiplied by the radiative efficiency of CO_2. This ratio's numerator is the "absolute GWP" of CH_4 and its denominator is the "absolute GWP" of CO_2.

- **Greenhouse Gas (GHG)**

A gas that absorbs radiation at specific wavelengths within the spectrum of radiation (infrared radiation) emitted by the Earth's surface and by clouds. The gas in turn emits infrared radiation from a level where the temperature is colder than the surface. The net effect is a local trapping of part of the absorbed energy and a tendency to warm the planetary surface. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.

- **Intergovernmental Panel on Climate Change (IPCC):**

The IPCC's mandate is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts, and options for adaptation and mitigation. The IPCC does not conduct any research nor does it monitor climate related data or parameters. Its assessments are primarily based on scientific and technical publications whose scientific value is widely recognised. The IPCC was created in 1988 at the request of the G7 (now the G8) by two UN bodies: the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP).

The IPCC is organised in three working groups:

Group I examines the physical and ecological aspects of climate change;
Group II examines impacts, vulnerability and adaptation to climate change;
Group III examines ways to attenuate (mitigate) climate change.
It also has a Task Force on National Greenhouse Gas Inventories (TFI) that produces methodology guides for these inventories. Each working group (and the task force) has two co-chairs, one representing developed countries and the other representing developing countries.

- **Lifetime**

In general, lifetime denotes the average length of time that an atom or molecule spends in a given reservoir, such as the atmosphere or oceans. It is not to be confused with the response time of a perturbation in concentration. CO_2 has no single lifetime.

- **ppm:** part per million.

- **ppmv:** part per million by volume.

- **Radiative Efficiency**

The radiative efficiency of a greenhouse gas, expressed in W/m2/ppm, measures the perturbation of the climate generated by introducing into the atmosphere one part per million of additional mass of the concentration of this gas in the atmosphere.

- **Radiative Forcing**

A simple measure of the importance of a potential climate change mechanism. Radiative forcing is the perturbation to the energy balance of the Earth-atmosphere system (in W/m2) following, for example, a change in the concentration of carbon dioxide or a change in the output of the Sun. The climate system responds to the radiative forcing so as to re-establish the energy balance. A positive radiative forcing tends to warm the surface and a negative radiative forcing tends to cool the surface. The radiative forcing is normally quoted as a global and annual mean value. A more precise definition of radiative forcing, as used in IPCC reports, is the perturbation of the energy balance of the surface-troposphere system, after allowing for the stratosphere to re-adjust to a state of global mean radiative equilibrium (see Chapter 4 of IPCC94). Sometimes called “climate forcing”.

- **Scenario**

A plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces (e.g., rate of technological progress, prices). Note that scenarios are neither predictions nor forecasts.

- **Solar Radiation**

Short wave radiation (0.4 to 0.8 µm) emitted by the Sun. It differs from terrestrial infrared radiation (see that term) because of the difference in temperature between the Sun and the Earth-atmosphere system.

- **Stratosphere**

The highly stratified and stable region of the atmosphere above the troposphere (see that term) extending from about 10 km to about 50 km in altitude.

- **Terrestrial Infrared Radiation**

Long wave radiation (approximately 10 µm) emitted by the Earth’s surface, the atmosphere and clouds. Infrared radiation, governed by the temperature of the Earth-atmosphere system, has a spectrum (range of wavelengths) different from that of solar radiation (see that term) because of the difference in temperature between the Sun and the Earth-atmosphere system.

- **Transient Climate Response**

The time-dependent response of the climate system (or a climate model) to a time-varying change of radiative forcing.

- **Troposphere**

The lowest part of the atmosphere from the surface of the Earth to about 10 km in altitude in mid-latitudes (ranging from about 9 km in high latitudes to about 16 km in the tropics on average) where clouds and “weather” phenomena occur. The troposphere is defined as the region where temperatures generally decrease with height.

- *United Nations Framework Convention on Climate Change (UNFCCC or FCCC),* adopted in Rio de Janeiro in 1992 by 154 countries and the European Community. It came into force on 21 March 1994. In 2004, it had been ratified by 189 countries. This convention is the first attempt within the UN to try to better understand what climate change is and how to remedy it.

It recognises three major principles:

- the precautionary principle;
- the principle of common but differentiated responsibilities; and
- the principle of the right to development.

The Convention contains all the principles in the final Rio de Janeiro Declaration and in Agenda 21, as well as the principles of international law, of which it is only one aspect.

This convention does not contain any legally binding targets.

It is frequently referred to as the “Climate Convention”.

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