THE IMPORTANCE OF A METHANE REDUCTION POLICY FOR THE 21ST CENTURY

Benjamin DESSUS, Bernard LAPONCHE, Hervé LE TREUT (October 2009)

(version BDBLHT5 établie le 8 mai 2012)

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1. INTRODUCTION

The anthropogenic emissions of methane (CH_4) are ranking second after the anthropogenic emissions of carbon dioxide (CO_2) in terms of potential impact on the global Earth radiative budget. They both produce an important greenhouse effect, with an associated global warming. Reducing the anthropogenic emissions of methane is then an important stake for climate change mitigation.

Compared to CO_2, CH_4 has a much higher radiative efficiency and a much shorter life-time in the atmosphere. As a consequence, the climatic impact of the relative emissions and emission reductions of these two gases are very different, depending on the period of time considered for their assessment.

In order to define a common unit for the emissions of all greenhouse gases, the Intergovernmental Panel on Climate Change has proposed an index named *Global Warming Potential (GWP)*. Its last review an definition can be found in the IPCC AR4 (IPCC[1], 2007). The GWP of CH4, or any other gas, is the time-integrated radiative forcing of a pulse emission of 1 tonne, relative to that of CO2, chosen as a reference gas. The integration is carried out over a time span which starts on the emission year and is limited by a time horizon chosen for its relevance for climate impact studies. The time horizon of 100 years is almost universally retained, leading to adopt the equivalence of 1 ton of CH4 to 21 tons of CO2, or 21tons of "CO2 equivalent".

There is currently a debate on the ability of this simple GWP concept to describe adequately the effects of the different gases under different mitigation strategies. Public action to curve down greenhouse gases may target different time scales, and different climate parameters. A recent IPCC expert meeting (IPCC, 2009) has concluded that, while GWP is a useful index, defined in a clear and physical manner, and improved by a continuous review process, it has not been designed to address the whole range of policies and is not adequate to deal with some of them. There is a concern about the best way to include the role of short-lived pollution, which is reflected in many of the papers presented at the IPCC Expert Meeting (IPCC, 2009). Focusing again on methane, and depending on the context, the CO2 equivalent value of 21 may appear too large or too small, with foreseeable consequences on the negotiations and policies. On one side, the surface temperature of the Earth, at a given time, is largely at equilibrium with the concentration of all greenhouse gases, including methane. As the concentration due to a pulse of methane declines very rapidly with time, the integration concept associated to GWP does not provide a correct assessment of this temperature. It is the reason why a different concept, the Global Temperature Potential (GTP) has been proposed as more suitable for this purpose (Shine et al, 2005). A detail computation of the GTP would involve a model of surface temperature evolutions, but the GTP of CH4 at year T may be approximated as the radiative forcing from the CH4 concentration that would result from a pulse emission of 1 tonne after T years, compared to that of a pulse of 1 tonne of CO2 after the same T years. On one side, we may think that GTP is better suited to estimate the impact of methane policies, because one of the reasons why we need short-term actions to curb down methane is precisely the fear of seeing the global earth temperature rising above the 2°C level. On the other side, instantaneous surface temperature is not the only parameter describing climate change. There are other parameters in the climate system that may depend more critically on the integration of the radiative forcing than its instantaneous value. This is probably the case of the deeper ocean thermal expansion, or large icecap melting, two processes which are essential in producing irreversibility in the climate change.

[1] IPCC : Intergovernmental Panel on Climate Change

In this paper we wish to address another concern, which has not received much attention while we think it has large implications: the "pulse" concept is clearly inadequate to describe current mitigation actions and the common practice of policy makers. In fact, almost all the emission mitigation programmes from international and national instances, whether already effective or considered for future action, correspond to emission reductions which should last at least several decades (building insulation, fossil fuel substitutions in power plants, etc.). Furthermore, the national programmes take as an implicit hypothesis that these reduction policies will perpetuate: at the end of a given action, a new reduction action is supposed to begin, at least equally effective, and hopefully more effective. So we have to consider that the mitigation measures we wish to evaluate will most generally perpetuate almost indefinitely. In addition, defining a methane (or CO2) reduction programme involving new initiatives every year (new plant rehabilitations for example) every year induces a continuous increase of this methane reduction.

Opening a debate on a new definition of the GWP is troublesome for at least two reasons: (i) it may undermine international agreements that have been slow to construct; (ii) it may be seen in some cases as an incentive to substitute easier short-term strategies to the absolutely necessary reduction of CO_2 emissions, which carry the dominant and lasting impacts on climate. But CO2 and CH4 reductions are not in competition one against the other: they generally concern different economic actors and should be encouraged simultaneously, because we know that we need all possible actions to curb down climate warming. Therefore whatever index we use, we should be fully conscious of its impact on a given type of policies. The aim of the paper is to analyse the consequences of using different metrics on CH4 mitigation policies,

In paragraph 2, we redefine GWP, GTP, and introduce a modified definition of those metrics to assess the relative role of lasting emissions (or reversely, lasting mitigation) rather than pulse emissions (or reversely, pulse mitigation) of CO2 and CH4, from a short (2030) to long-term (>2100) perspective. In paragraphs 3, 4 and 5 we review the different methane mitigation options which might be better targeted by a more specific definition of the methane CO2 equivalent.

2. Calculation of the Global warming and global temperature potentials

2.1 Introduction and basic data

The global warming potential of the different atmospheric gases has been defined by the IPCC (1995) as a simple and synthetic measure of their climatic impact relative to carbon dioxide (CO_2). This global warming potential is the basis on which the emission of those gases is measured in "CO_2-equivalent" units, a notion widely used to dimension public policies.

In the following paragraphs, we use the same equations which underline this definition, equations which have been updated in the successive IPCC reports (IPCC, 2001, 2007), to study the sensitivity of these concepts to different possible choices or assumptions. The objective of this section is not to provide original results (we have on the contrary made sure that we were able to reproduce exactly the IPCC results) but to establish a few reference numbers.

The last IPCC report (IPCC, 2007[2]) provides the main data necessary to compute global warming potentials:

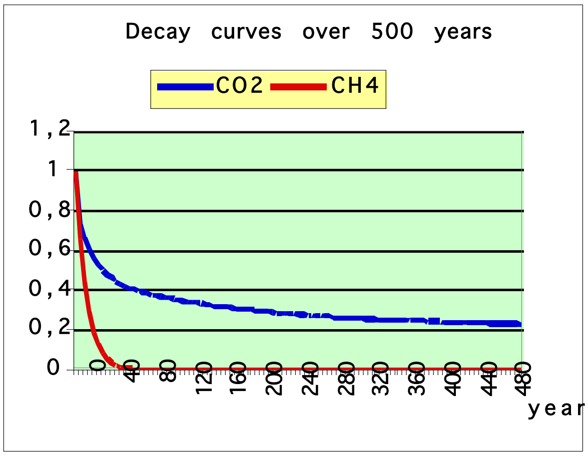
a) The ratio of the radiative efficiency of 1 mass unit of CH4 (a_{CH4}) over that of 1 mass unit of CO2 (a_{CO2}): 72.68 (these radiative efficiencies are respectively 3.7 x 10^{-4} per ppb for CH4 and 1.4 x 10^{-5} per ppb for CO2).

b) The correction factor due to the indirect effects of CH4 emissions through the changes in OH, tropospheric ozone and stratospheric vapour concentrations following CH4 decay, equal to 1.3752.

[2] IPCC "Climate Change 2007: - Working Group I : The Scientific Basis" (Chapter 2, sub-chapter 2.10).

c) The characteristic decay with time of CO2 and CH4 concentrations, after a pulse emission of 1 mass unit in the atmosphere at year 0, noted respectively $C_{CH4}(t)$ and $C_{CO2}(t)$, and illustrated in Figures 1 and 2.

Figures 1 & 2 : Decay curves of CO2 and CH4 in the atmosphere



2.2 GWP and GTP values of CH4 at different time horizons : pulse emissions

The Global Warming Potential GWP and the Global Temperature Potential GPT of CH4, presented in the Introduction, are both defined by reference to a pulse emission of, respectively, a mass unit of CH4 and CO2.

The GWP (Global Warming Potential) value of CH4 at a given time horizon, defined by a year TH, is equal to the ratio of the radiative efficiencies of 1 tonne of CH4 and 1 tonne of CO2, that is 72.68, multiplied by the correction factor 1.375, multiplied by the ratio of the integrated values over the 0-TH period of the respective concentrations of CH4 and CO2 resulting from the initial pulse emission.

$$\mathrm{GWP}_{\mathrm{CH4\,(TH)}} = 1.375 \text{ x } \frac{\int_0^{TH} a_{CH4} \times C_{CH4}(t)dt}{\int_0^{TH} a_{CO2} \times C_{CO2}(t)dt} = 1.375 \text{ x } 72.68 \text{ x } \frac{\int_0^{TH} C_{CH4}(t)dt}{\int_0^{TH} C_{CO2}(t)dt}$$

For time horizons of years 20, 100 and 500, the values of the GWP for CH4 calculated by this formula are respectively 72, 25 and 7.6, as presented by IPCC (Table 2.14 of reference 2).
The values of GWP from time horizon 1 year to time horizon 500 years are displayed in Table 1.
In this calculation, the 1.375 correction factor for CH4 indirect effects is applied from the very beginning of the period, due to the very sharp decline of CH4 after the pulse emission at year 0.

Table 1 : GWP of CH4 (pulse emission) value at different time horizons

Time horizon (year)	**1**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**50**	**100**	**500**
GWP	103	101	90	80	72	64	58	49	42	25	7.6

The GTP (Global Temperature Potential) of CH4 value at a given time horizon, which is also noted here as year TH, is equal to the ratio of the radiative efficiencies of 1 tonne of CH4 and 1 tonne of CO2, that is 72.68, multiplied by the correction factor 1.375, multiplied by the ratio of the respective concentrations of CH4 and CO2 at year TH resulting from the pulse emissions at year 0 of 1 tonne of CH4 and 1 tonne of CO2. The above remark on the use of the correction factor 1.375 is also valid for the GTP calculation.

$$GTP_{CH4}(TH) = 1.375 \text{ x } \frac{a_{CH4} \times C_{CH4}(TH)}{a_{CO2} \times C_{CO2}(TH)} = 1.375 \text{ x } 72.68 \text{ x } \frac{C_{CH4}(TH)}{C_{CO2}(TH)}$$

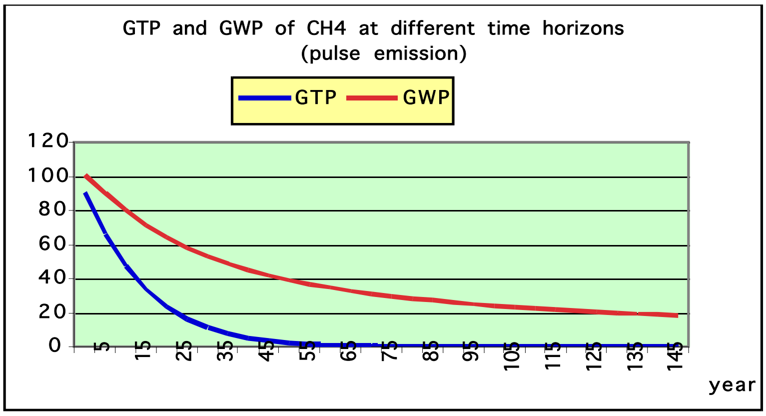
The value of CH4 GTP decreases very quickly with time horizon, from 105 (time horizon of 1 year) to 34 (time horizon 20 years) and 0.07 (time horizon of 100 years).
The values given in Table 2 cover a range of time horizons from 1 year to 500 years.

Table 2 : GTP of CH4 (pulse emission) value at different time horizons

Time horizon (year)	1	5	10	15	20	25	30	40	50	100	500
GTP	105	90	66	48	34	24	16	7.8	3.6	0.07	0

The values of GWP and GTP, which are initially very similar, diverge rapidly with increasing time horizons (Figure 3). The ratio GWP/GTP grows from 1.1 (time horizon of 5 years) to 2.1 (time horizon of 20 years), and then 12 (time horizon of 50 years), up to 357 (time horizon of 100 years).

Figure 3: GTP and GWP of CH4 at different time horizons (pulse emission)



2.3 The global warming and temperature potentials for sustained or permanently avoided emissions

The GWP and GTP constitute two alternative metrics for comparing the consequences at of pulse emissions of the same mass of CH4 (or other greenhouse gases) and CO2.
In order to assess the potential effects of greenhouse gases emissions reduction policies, it is also important to compare at different time horizons, and with the same basic assumptions, the impact of CH4 and CO2 sustained emissions, or, reversely, of permanently avoided emissions of CH4 and CO2.
More specifically we define here sustained or permanently avoided emission for a period going from year 1 to year TH, as a constant annual source of 1 ton of CH4 and CO2, which is either emitted or suppressed. This permanently avoided emission is of course an emission which would continue if the policy under evaluation was not implemented.

In order to avoid confusion with the pulse emission potentials GWP and GTP, the new ratios calculated for sustained or permanently avoided emissions are herewith called GWPS (*Global Warming Potential for Sustained emission*) and GTPS (*Global Temperature Potential for Sustained emission*).

The GWPS of CH4 at time horizon TH is the ratio of the integrated warming effects over the period 0-TH of the emissions at year T (varying from 0 to TH) of, respectively, 1 tonne of CH4 and 1 tonne of CO2 per year during this period. This definition can also be applied to avoided emissions.

$$\mathrm{GWPS}_{\mathrm{CH4}}(\mathrm{TH}) = 1.375\mathrm{x}\,\frac{\int_0^{TH}\left[\int_T^{TH} a_{CH4}\times C_{CH4}(t-T)dt\right]dT}{\int_0^{TH}\left[\int_T^{TH} a_{CO2}\times C_{CO2}(t-T)dt\right]dT} = 1.375\mathrm{x}72.68\ \mathrm{x}\ \frac{\int_0^{TH}\left[\int_T^{TH} C_{CH4}(t-T)dt\right]dT}{\int_0^{TH}\left[\int_T^{TH} C_{CO2}(t-T)dt\right]dT}$$

By changing the variables: t' = t-T, and T' = TH-T, the double integration for the numerator (or the denominator) can be written as:

$$\int_0^{TH}\left[\int_T^{TH} C_{CH4}(t-T)dt\right]dT = \int_0^{TH}\left[\int_0^{T'} C_{CH4}(t')dt'\right]dT',$$

which provides the following final equation for GWPS:

$$\mathrm{GWPS}_{\mathrm{CH4}}(\mathrm{TH}) = 1.375\ \mathrm{x}\ 72.68\ \mathrm{x}\ \frac{\int_0^{TH}\left[\int_0^{T'} C_{CH4}(t')dt'\right]dT'}{\int_0^{TH}\left[\int_0^{T'} C_{CO2}(t')dt'\right]dT'}$$

The values of GWPS of CH4 are respectively 84, 59, 39 and 13 for time horizons 20, 50 , 100 and 500 years. For the same time horizon, GWPS values are well over those of GWP (by 17% at year 20 and 56% at year 100).
Table 3 shows the value of GWPS for time horizon varying from year 1 to year 500.

Table 3: GWPS of CH4 (sustained emission or permanently avoided emission) at different time horizons

Time horizon TH (year)	**1**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**50**	**100**	**500**
GWPS	102	103	97	91	84	79	74	65	59	39	13

We can similarly define GTPS, as the impact on surface temperature TH years after the initiation of a sustained emission (or mitigation) of both CH4 and CO2. That means that GTP (TH) is equal to the ratio of the radiative efficiencies of 1 tonne of CH4 and 1 tonne of CO2, that is 72.68, multiplied by the correction factor 1.375, multiplied by the ratio of the integrated values over the 0-TH period of the respective concentrations of CH4 and CO2 resulting from the emission (or avoided emission) at each year t.

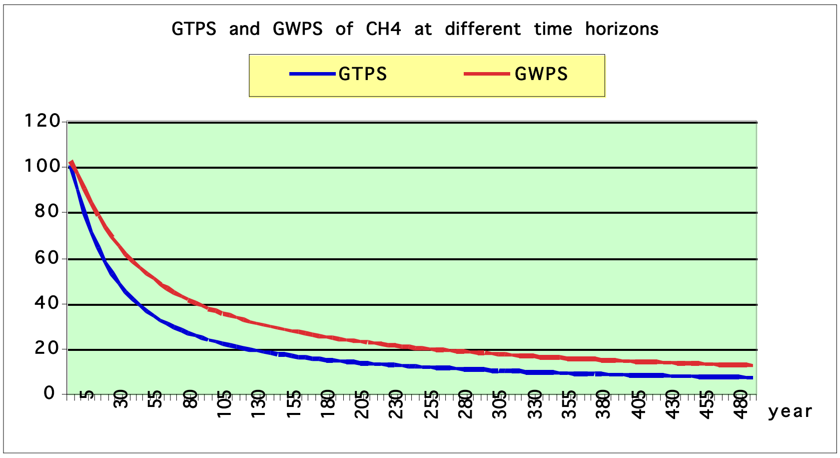
$$\mathrm{GTPS_{CH4}(TH)} = 1.375 \times \frac{\int_0^{TH} a_{CH4} \times C_{CH4}(t)dt}{\int_0^{TH} a_{CO2} \times C_{CO2}(t)dt} = 1.375 \times 72.68 \times \frac{\int_0^{TH} C_{CH4}(t)dt}{\int_0^{TH} C_{CO2}(t)dt}$$

This value is exactly equal to that of the GWP (pulse emission) at the same time horizon, as demonstrated by Dufresne (2009)[3]. For time horizons of years 20, 100 and 500, the values of the GTPS of CH4 calculated by this formula are then respectively 72, 25 and 7.6.

These values for time horizons from year 1 to year 500 are those presented in Table 1.
We can note that with increasing time horizons, the values of GTPS are rapidly much higher than the values of GTP. The ratio GTPS/GTP is 1.1 for year 5, 2.1 for year 20, 12 for year 50 and 357 for year 100. The values of GTPS are lower than the values of GWPS for the same time horizon, but with less important factors than above: the ratio GWPS/GTPS is 1.02 for year 5, 1.17 for year 20, 1.40 for year 50, and 1.56 for year 100.

In summary, when dealing with sustained emissions or permanently avoided emissions, the potential which best describes the impact of CH4 on temperature is considerably higher than the GTP value. The curves of the values of GTPS and GWPS at different time horizons from year 1 to year 500 are shown in Figure 4.

Figure 4 : GTPS and GWPS for CH4 at different time horizons (sustained or permanently avoided emissions)



2.4 Comparison of two emissions reduction programmes for CH4 and CO2

The integration effect associated with the permanent nature of avoided emissions, is of course enhanced if we imagine a situation where the CO2 and CH4 emissions are reduced by programmes of ever increasing importance. We can define new indices GWPPro (*Global Warming Potential for reduction emission Programme*) and GTPPro (*Global Temperature Potential for reduction emission Programme*), to compare the effect of programmes in which a new action reducing permanently 1t of carbon dioxide or methane is started every year.

GWPPro of CH4 at time horizon TH is the ratio of the global warming effect of CH4 and CO2 avoided emissions over the 0-TH period. Its value is equal to the ratio of the radiative efficiencies of 1 t of CH4 and 1 t of CO2, that is 72.68, multiplied by the correction factor 1.375, multiplied by the

[3] Jean-Louis Dufresne « L'utilisation du potentiel de réchauffement global pour comparer les emissions de methane et de dioxide de carbone", *La Météorologie n° 64 – Février 2009.*

ratio of the sums of the integrated and cumulated values over the 0-TH period of the concentrations of CH4 and CO2 for each year t (t varying from 0 to TH).

$$GWPPro_{CH4}(TH) = 1.375 \text{ x } \frac{\int_0^{TH}\int_0^{T}\int_0^{\theta} a_{CH4} C_{CH4}(t)dt}{\int_0^{TH}\int_0^{T}\int_0^{\theta} a_{CO2} \times C_{CO2}(t)dt} = 1.375 \text{ x } 72.68 \text{ x } \frac{\int_0^{TH}\int_0^{T}\int_0^{\theta} C_{CH4}(t)dt}{\int_0^{TH}\int_0^{T}\int_0^{\theta} C_{CO2}(t)dt}$$

GTPPro at time horizon TH is the ratio of the global temperature effect of CH4 and CO2 avoided emissions over the 0-TH period. Its value is equal to the ratio of the radiative efficiencies of 1 t of CH4 and 1 t of CO2, that is 72.68, multiplied by the correction factor 1.375, multiplied by the ratio of the cumulated values over the 0-TH period of the integrated values of, respectively, CH4 and CO2 concentrations over the t-TH period (t varying from 0 to TH).

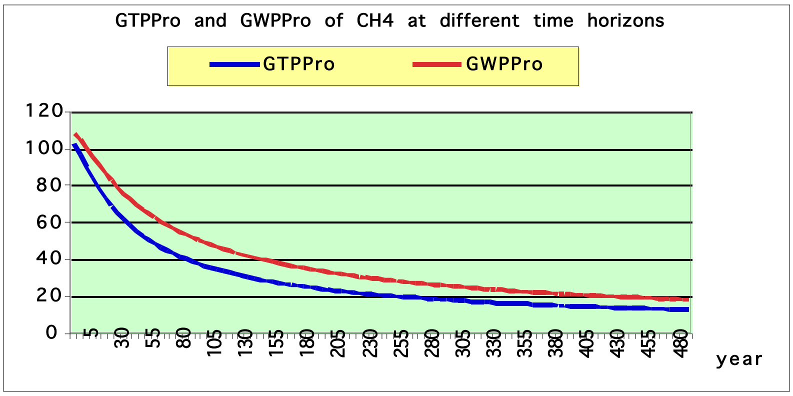
$$GTPPro_{CH4}(TH) = = 1.375 \text{ x } \frac{\int_0^{TH}\int_0^{T} a_{CH4} \times C_{CH4}(t)dt}{\int_0^{TH}\int_0^{T} a_{CO2} \times C_{CO2}(t)dt} = 1.375 \text{ x } 72.68 \text{ x } \frac{\int_0^{TH}\int_0^{T} C_{CH4}(t)dt}{\int_0^{TH}\int_0^{T} C_{CO2}(t)dt}$$

The value of GTPPro at time horizon TH is then equal to the value of GWPS at the same time horizon.
At time horizons year 20, year 50 and year 500, the values of GWPPro are respectively 96, 73 and 18 and the values of GTPPro are respectively 84, 59 and 13.
The GWPPro and GTPPro values for different time horizons are shown in Table 4 and Figure 5.

Table 4: GWPPro and GTPPro for two permanent emission reduction programmes of 1 tonne of CO2 and 1 tonne of CH4 each year from year 0.

Time horizon (year)	**1**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**50**	**100**	**500**
GWPPro	106	108	105	101	96	91	87	79	73	52	18
GTPPro	102	103	97	91	84	79	74	65	59	39	13

Figure 5: GTPPro and GWPPro for two permanent emission reduction programmes of 1 tonne of CO2 and 1 tonne of CH4 each year from year 0.



When dealing with programmes which aim to reduce continuously CH4 emissions for several decades, as usually undertaken by countries, the warming and temperature potential of CH4 which have to be taken into account are different from the warming and temperature potentials calculated for pulse and permanent emission reductions, considerably higher than the GTP (pulse emission), more important at 20 years by a factor of about 3.6 (from 3.4 to 3.8) than the GWP value at 100 years (25), and a factor 4.3 to 4.0 with the currently used GWP value for methane (21). In the present example, even for a time horizon of 50 years this ratio remains 2.8 to 3.5 higher than the currently used GWP value of methane (21).

It clearly appears that whatever the kind of global warming concern (temperature at a given horizon or heat transfer during a given period) the present way to take into account methane emissions under-estimates seriously the importance of CH4 reduction programmes, not only for the short and medium term (20 to 50 years) but also significantly at a longer term (a ratio of 1.9 to 2.5 for 100 years).

3. ILLUSTRATIVE EXAMPLES OF METHANE EMISSION REDUCTION PAST POLICIES IMPACTS ON CLIMATE CHANGE

In order to illustrate these points it is interesting to examine what effects will have the methane policies implemented in the recent past years by various countries over the course of the present century.

3.1 The case of Germany and France

In France and Germany, the policies implemented between 1990 and 2004 have led to very different changes in methane and carbon dioxide emissions (Table 5).

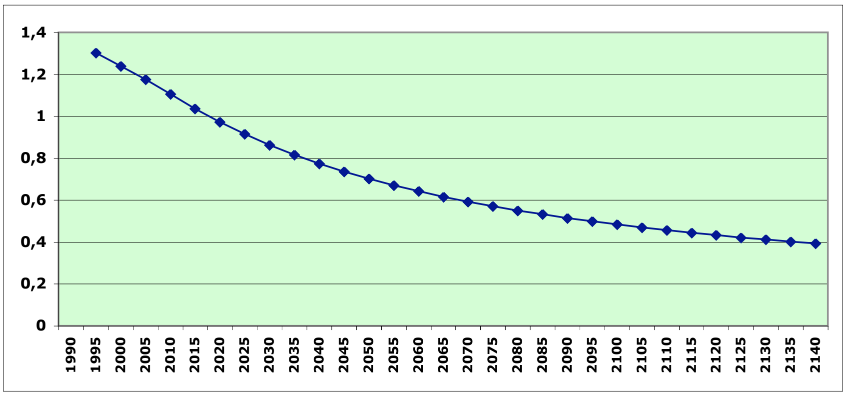
Table 5: German and French CH4 and CO2 emissions from 1990 to 2004

CH4 1000 tonnes	**1990**	**2004**	**Difference (%)**
Germany	**4157**	**2376**	**-43%**
Energy	*918*	*697*	*-24%*
Agriculture	*1420*	*1100*	*-23%*
Waste	*1820*	*577*	*-68%*
France	**3243**	**2980**	**-8%**
Energy	*495*	*454*	*-8%*
Agriculture	*2130*	*1951*	*-8,4%*
Waste	*576*	*543*	*-6%*
CO2 Million tonnes	**1990**	**2004**	**D %**
Germany	**976**	**839**	**-14%**
France	**358**	**345**	**-4%**

A very large difference between the two countries occurred in the changes in methane emissions: a more than 40% reduction over 14 years in Germany, compared to 8% in France. While the difference

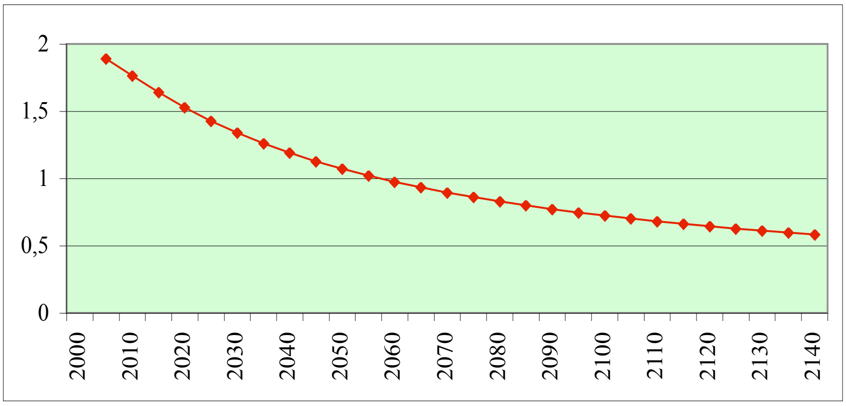
is relatively easy to explain for the energy sector because of the partial abandon of coal in Germany and the closing of mines, in other sectors it is explained only by the two countries' different policies (e.g. waste management). Over the course of the period, Germany reduced its CO2 emissions by 14%, France by 4%. We can estimate, for each of the two countries, their contributions to the fight against global warming brought about by these reductions, hypothesising that they will remain in effect until the end of this century.
The application of the comparison of two programmes presented above shows that during the 21st century, the methane reductions obtained in Germany from 1990 to 2005 will have consequences similar to those of the CO2 reductions over the same period until 2020, and still 70% of the latter in 2050 on the cumulative radiative forcing reductions. They will fall to approximately 40% in 2150 (Figure 6).

Figure 6: Comparative effectiveness of methane and CO2 reduction policies in Germany from 1990 to 2005 on avoided radiative forcing from 1990 to 2140.



In France, the methane reductions obtained from 1990 to 2005 will have consequences on cumulative radiative forcing more important than those of the CO2 reductions over the same period until 2070, and still 60% of the latter in 2150 (Figure 7).

Figure 7: Comparative effectiveness of methane and CO2 reduction policies in France from 1990 to 2005 on avoided radiative forcing from 1990 to 2150.



In both cases, the contribution of reducing methane emissions to the reduction in the overall radiative balance is far from negligible compared to CO2 reduction, even in the case of Germany that had, during the same period, managed to reduce its CO2 emissions by 14% (1% per year).

3.2 The case of Mexico

From 1990 to 2002, in Mexico, carbon dioxide emissions increased by 28% and methane emissions by 34%. This sharp growth in methane emissions is mostly due to the establishment over the period of household waste collection, landfill disposal systems and wastewater treatment plants (Table 6). 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.

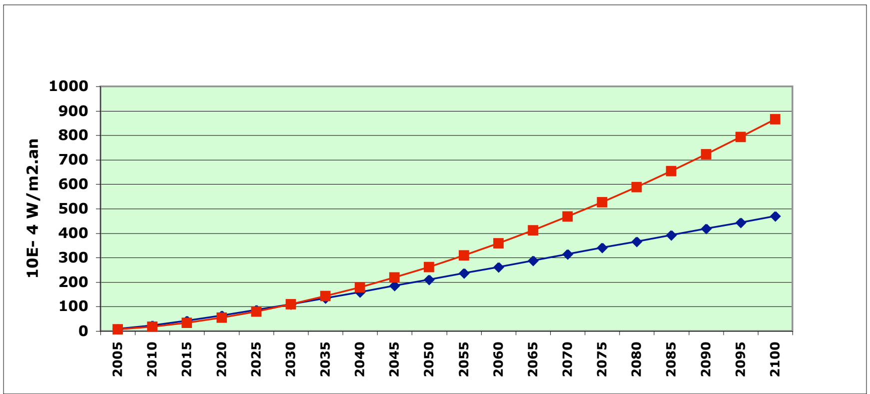
Table 6 : CO2 and CH4 emissions from 1990 to 2002 in Mexico

Mexique	1990	2002	D%ifference (%)
CO2	283	393	+28%
CH4	4.5	6.8	+34%
From which			
Fugitive emissions	1.57	1.85	+18%
Waste & water treatment	1.45	3	+207%

Source: unfccc.int/national_reports/non-annex_i_natcom/items/2979.php

The calculation of the impact of the emissions during this time on the intensification of the cumulative radiative forcing during the century shows that, in 2020, the effects of additional methane emissions are 15% greater than those caused by CO2 emissions, equivalent in 2035, still 65% in 2075, and 54% in 2100 (Figure 8).

Figure 8: Comparative cumulative radiative forcing to 2100 of additional CH4 and CO2 Emissions from 1990 to 2002 in Mexico



These three examples show that the reductions or additional methane emissions performed by either developed or emerging countries for the past 10 years will never be negligible for climate change during the present century.

3.3 Future programmes

It is also interesting to review the contribution of future reduction programmes on climate change mitigation, for example for China.
China published its first national strategy to fight climate change on June 4, 2007. Elaborated by the National Development and Reform Commission (NDRC2007), China's National Climate Change Programme (NCCP) contains a series of measures and quantitative targets for 2010. In particular, the objective of avoided emissions in 2010 in the energy sector (Table 7) is 750 Mt of CO2 and 10 Mt of CH4 from CH4 recovery from coal mines.

Table 7: Avoided greenhouse gases (Mt) induced by China NCCP in the energy field in 2010.

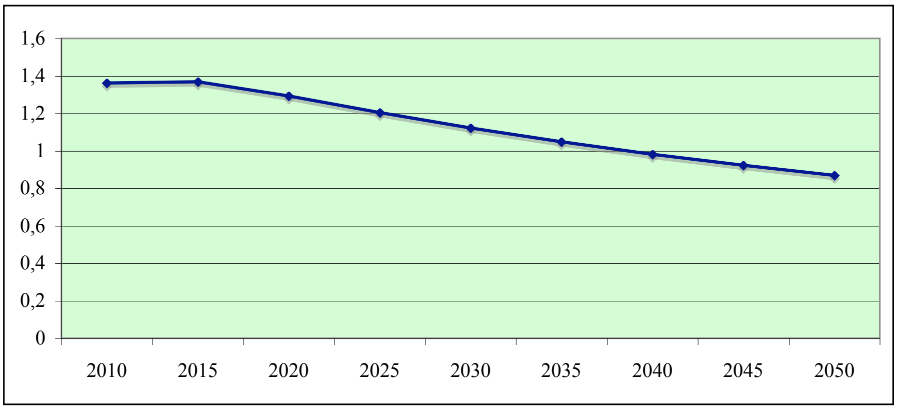
Economic Sector/ Technology	Avoided emissions in 2010 (Mt)
Hydro	500 (CO2)
Nuclear	50 (CO2)
Power plants	110 (CO2)
Recovering CH4 from coal mines	10 (CH4)

Renewables	90 (CO2)
Total	**750 (CO2), 10 (CH4)**

Source : CITEPA, July 2007,Chine : Energie et émissions de gaz à effet de serre,

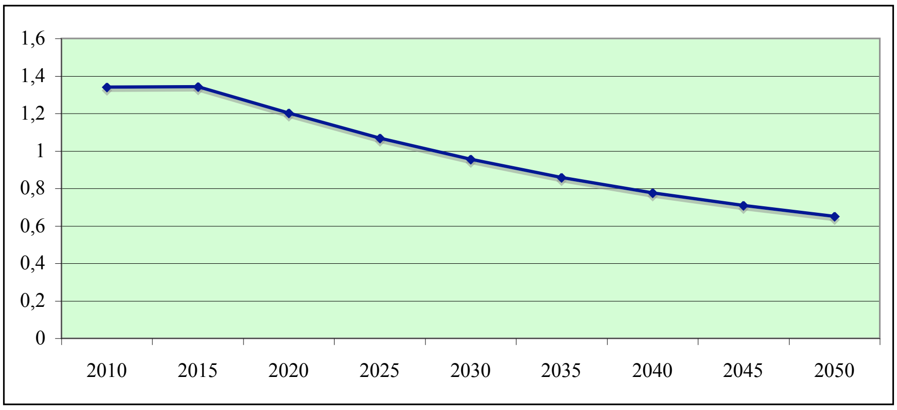
Until 2040, the mine firedamp capture policy is as effective as all the other energy diversification policies undertaken, and still 85% as effective in 2050 on the cumulative radiative forcing (Figure 9).

Figure 9: Comparative effectiveness of methane and CO2 programmes of Chinese NCCP on cumulative radiative forcing until 2050



The same kind of results can be obtained for Earth temperature: until 2028, the mine firedamp capture policy is as effective as all the other energy diversification policies undertaken, and still 60% as effective in 2050 on Earth temperature control (Figure 10).
The success of this policy is therefore crucial in the medium term for this country where energy needs are growing rapidly.

Figure 10: Comparative effectiveness of methane and CO2 programmes of Chinese NCCP on earth temperature control until 2050



These retrospective and prospective examples show the importance and diversity of the options to fight climate change, which are open to countries with highly diverse geographic and economic characteristics, when it comes to reducing methane emissions.

4. THE MAGNITUDE OF THE STAKES AND CONSEQUENCES OF A GLOBAL METHANE EMISSION REDUCTION POLICY IN THE COMING DECADES

4.1 Breakdown of Methane Emissions by Sector and by Region

Overall methane emissions in the atmosphere are estimated at 500 Mt (million tons) 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 comes from fossil energy combustion, the amounts and emissions of which 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 are, however, overall indications that provide approximate magnitudes of these emissions for the breakdown by sector of activity and major region (Tables 8 and 9).

Table 8: Economic sector breakdown of world methane emissions

CH4	Million tonnes	%
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 Working Group 3 Summary for Policy Makers, 2007.

Table 9: World CH4 emissions by region

1990	OECD Countries	Asia Non OCDE	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 (38%), with the pre-eminence of stock farming, except in Asia where rice cropping accounts for two-thirds of agricultural emissions. Leakage from energy systems comes next (33%). The third largest source consists of emissions from household waste landfills (23%). The last (6%), 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 comes 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). 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, about two-thirds of the stock farming's emissions come from animals' enteric fermentation and one-third from manure and the slurry (European Commission, 2007[4]). 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. Because of this, rice cropping is the second largest producer of methane worldwide, producing 60 million tons per year, right behind ruminant farming. However, alternative irrigation techniques, in particular seasonal drainage, could be

[4] Annual European Community greenhouse gas inventory 1990–2005 and inventory report 2007 Submission to the UNFCCC Secretariat.

used to limit this problem (Le Mer and Roger, 2001[5])

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 transport and distribution system, and, marginally, from the automobile sector. Worldwide, these emissions have increased by more than 15% since 1990.

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 (Shi Su et al, 2005[6]). There are two types of coalmines: surface mines and underground mines. 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. 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.

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[7]). There are no recent precise national 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 Mt of fugitive CH4 emissions for a coal production of approximately 1,100 Mt. In 2006, production—at 2,400 Mt—had more than doubled. From this, one can therefore infer approximately 15 Mt of CH4 emissions. This order of magnitude is compatible with the objectives set by China in its national plan to fight the greenhouse effect by 2010 , which envisages capturing and recovering 10 million tons of methane from its coalmines. As China produces approximately 40% of the world's coal, one can estimate the scope of fugitive methane emissions in the coal sector worldwide at 30 to 35 million tons of CH4.

Oil and Natural Gas

The main 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. 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 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 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 Mt (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, fugitive emissions are 5 Mt of CH4 (1%) (EPA, 2009[8]). Extrapolated to a production of approximately 2,000 Mt of CH4, fugitive methane emissions from the gas system could therefore range between 35 and 40 million tons

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5 Pierre Roger et Jean Le Mer, Laboratoire de microbiologie IRD Université de Provence, CESB/ESIL « Réduire l'émission de méthane par les rizières ».

6 Shi Su, a. Beath, Hua Guo, C. Mallett (2005), "An Assessment of Mine Methane Mitigation and Utilisation Technologies", Progress in Energy and Combustion Science 31, 123–170, Elsevier.

7 Ibidem 6.

8 Detailed inventory of US emissions (www.epa.gov/climatechange/emissions/usinventoryreport.html).

of CH4.
Fugitive CH4 emissions from the oil system also vary greatly from country to country. In the United States, leaks are minor: approximately 1.5 Mt of CH4, compared to the country's production of approximately 350 Mtoe/year (EPA, 2009[9]). In Saudi Arabia, however, CH4 fugitive emissions linked to the oil system were 3.5 Mt in 1990, for a production of approximately 420 Mtoe/year, and thus more than double in proportion to production (Saudi Arabia, 2005[10]). Based on this, losses from the upstream sector can be estimated at between 4 and 10 Mt per Gtoe of oil, with an average of close to 8 Mt, or approximately 30 Mt of CH4 for current oil production, to which one must add the fugitive emissions of 10 to 15 Mt of CH4 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 Mt of CH4 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. In highly developed countries such as the United States, CH4 emissions from household waste landfills release as much CH4 as ruminants' enteric fermentation: 6 Mt of CH4 (UNFCCC, 2009[11]). In the European Union (27 countries), CH4 emissions from landfills still account for approximately 4 Mt of CH4 in 2008, despite the European directive in force on landfill methane recuperation (Skovgaard et al, 2009[12]).

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 Mt of CH4 out of the approximately 15 Mt currently emitted (65%), allow one to extrapolate a minimum reduction of 20 Mt of CH4 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 Mt of CH4 per Giga tonne of oil) and gas (1.3% of leaks), one could limit emissions to approximately 25 Mt of CH4 for the gas sector and 25 Mt for the oil sector. All in all, one can therefore reasonably envisage the reduction of the world energy system emissions by 50 Mt of CH4 in the medium term.
In the household waste sector (around 80 Mt CH4 emitted), there are numerous methods to reduce methane emissions: covering landfills and capturing methane (as demonstrated on numerous sites in Europe), incineration (as long as environmental and sanitary problems are resolved), use of methanization reactors, or waste composting. These solutions all make it possible to cut residual methane emissions to a few percentage points. CH4 emissions linked to urban waste could reasonably be reduced by approximately 40 to 45 Mt from the generalisation of these methods which have already been amply tested in Northern European countries.
In agriculture, rice production (approximately 600 million tons per year) is the source of approximately 60 million tons of CH4 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 receive financial incentives.
In the field of stock farming (approximately 80 million tons of CH4 emissions), experiments are,

[9] Ibidem 8.
[10] First national communication of the Kingdom of Saudi Arabia submitted to UNFCCC, 2005.
[11] unfccc.international_reports/non annex_1_natcom/items/2979php.
[12] Skovgaard, M., Hedal, N., Villanuueva, A., European Topic Centre on Resource and Waste Management and Møller Andersen, F. et Larsen, H. Risoe National Laboratory, Technical University of Denmark, "Municipal waste management and greenhouse gases", DTU ETC/RWM working paper 2008/1.

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 of herds worldwide. However, processing manure and slurry, whose emissions today account for approximately 25% of world emissions from stock farming (20 Mt of CH4), can be an important source of emission reductions. Effective techniques to do so exist and numerous manure and slurry methanization plants function in industrialised countries[13] and developing countries (China, India, Vietnam, etc.). The reasonably ***actualisable*** potential of this resource in the short an medium term (25% to 50%) represents an additional reduction of world methane emissions of 5 to 10 Mt of CH4.

At a global level, the order of magnitude of the identified possibilities of CH4 emission reduction for the world rank roughly from 100 to 115 Mt (Table 10). The reduction potential is therefore approximately 30% of current anthropogenic emissions (357 Mt).

Table 10: Potential magnitudes of world methane emission reductions in the short and medium term (10 – 30 years) by sector

SECTOR	REDUCTION POTENTIAL (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**

5. ECONOMIC ASPECTS

From the economic standpoint, the various technologies envisaged to reduce methane emissions have very different characteristics 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. 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. For instance, in the recent years in Europe, in the context of rising oil and natural gas prices, re-using landfill methane for thermal or electric purposes has been generally enough to make the project profitable. It is clear that this would not be the case with, for example, more CH4-sober cropping or stock farming practices, or landfill or mine methane emission flaring. In these cases, only incentives are likely to generate the necessary investments and practices.

5.1 Methane emission reduction policies

Thus, when one analyses the various sectors and technologies that intervene in reducing methane emissions, one can classify them in two main categories:

(a) Those that allow the production and use of a material good (an energy product) for which there is a market.

The corresponding projects 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:
i) The capture and re-use of landfill methane, either by post-filtering injection of the gas into natural gas networks, or by the processing and distribution of electricity and heat.

[13] Basic data for farm biogas plants in Germany, July 2005, ATEE Biogas Club, www.biogaz.atee.fr.

ii) Farm methane, 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 as in Germany[14]. 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 reducing CH4 emissions, one must therefore be very attentive to sealing the methanization system to prevent leaks that would lessen the interest of this additional biogas production.
iii) Capturing methane drained from coalmines before mining or after the closing of the mines.

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).

The corresponding projects notably include:
i) 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.
ii) The gas flared in the field in the oil sector, when the conditions for re-use are not met.
iii) Gas leakage associated with natural gas transportation, storage and distribution systems the reduction of which is not justified by commercial gains or safety concerns for natural gas distributors.
iv) Agricultural practices in rice cropping or stock farming that emit little methane and that do not result in improved yields or better productivity.

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.

In the current context, 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 a factor of 4 by 2050, large-scale CH4 action would make it possible to loosen the very strong time constraint on CO2 reductions, a large share of which require structural measures: insulating old buildings, 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 to fifteen years at generally modest cost. This is the case, in particular, for methanization 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 CO2 emissions, primarily linked to the energy system. However, the linkage of economic growth and CH4 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.

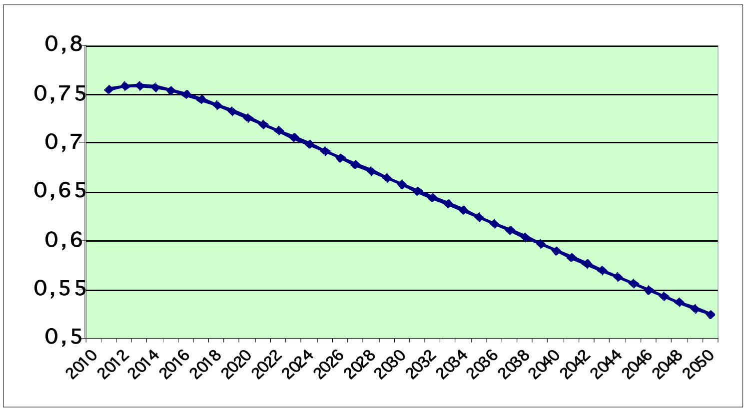
5.2 Two emission reduction scenarios at world level

To gain an awareness of the magnitude of the stakes at world level, it is interesting to compare two scenarios, which have the objective of lowering the emissions of CO2 or of CH4 in proportions required by the current objectives on global warming limitation. In the first scenario, S1, the emissions of the GHGs others than CO2 are maintained at their 2004 values, and CO2 emissions alone are

[14] Ibidem 13.

reduced by 30% compared to their 2004 level, which represent a reduction by some 15 Gt. This reduction is to take place over the 2010-2030 period in a linear progression of 750 Mt of CO2 per year. The second scenario, S2, consists of keeping the CO2 emissions at their 2004 values, and reducing methane emissions by 30% from 2010 to 2030 that is 110 Mt out of the 355 Mt emitted worldwide in 2004, as considered in the previous chapter. Such a programme can be envisaged over the same period of time as the first, with a linear progression of 5.5 Mt per year from 2010 to 2030.
By comparing the warming effects of both scenarios, we see that the S2 scenario (CH4 abatement) remains very effective until 2050: 72% as effective as the CO2 programme (S1) in 2020, 66% in 2030, 59% in 2040 and still 52% in 2050 (Figure 11).

Figure 11: Comparative effectiveness of 30% methane and 30% CO2 world reduction programmes before 2030 on cumulative radiative forcing until 2050



This means that a specific world programme of methane reduction (which is not the case for the time being) would be of a great importance for preventing global warming at medium term.

6. CONCLUSIONS FOR ACTION.

The 2007 IPCC report has confirmed that a global warming above 2°C would constitute a danger for our environment. This implies that climate change is an issue for a much sooner future than was considered by policy makers a decade ago. The report highlights the very short-term need to reach a turning point around 2020 and a 30% to 40% reduction in CO2eq global emissions in 2030 compared to its 1990 level, whereas world emissions are currently growing at a rate of about 3% per year. This highlights the necessity to put in place urgent, ambitious, and continuously strengthened policies, which would target all possible options to turn down greenhouse gas emissions.

In this short term context, it is more appropriate, as explained above, to appreciate the efficiency of CH4 and CO2 reduction policies through global warming indices such as GTPPro or GWPPro rather than the GTP or GWP pulse indices. The GWP index value of 21 generally taken into account by policy makers for the comparison of CH4 and CO2 underestimates the role of methane emission reduction programmes by a ratio of as much as 4 or 4,6 at 20 years for respectively GTP or GWP estimations, and still 1,9 or 2,5 at 100 years (Table 11).

Table 11: Under-estimation factor of CH4 linear programmes using "Kyoto" GWP 21

Time horizon (year)	**1**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**50**	**100**
GTPPro /GWP "Kyoto"*	4,86	4,9	4,62	4,33	4	3,76	3,52	3,1	2,8	1,86
GWPPro /GWP "Kyoto"*	5,05	5,14	5	4,81	4,57	4,33	4,14	3,76	3,48	2,48

** The value of GDP "Kyoto" is 21.*

Using a single index to favour the most relevant policies at different time scales therefore appears as an oversimplification, which may help clarify complex international negotiations, but may be detrimental for other useful and cost-effective actions. One possibility, as emphasized by Daniel et al (2009)[15], might be to have different baskets for the greenhouse gases of different time-life and to consider the relevant mitigation options within those baskets.
It would thus be very useful to promote an open debate on these physical basis in order to find a consensus on new equivalence coefficients for CH_4 more suitable to assess real global warming consequences with time of real emission's reduction programmes as they are envisaged by policy makers.

[15] Daniel, J.S., S. Solomon, and M. McFarland, 2009: A Limitation of Global Warming Potentials Revisited,in Expert Meeting on the Science of Alternative Metrics, Meeting Report, Edited by Plattner G.K., T. Stocker, P. Midgley, M. Tignor, IPCC, Geneva, p25.