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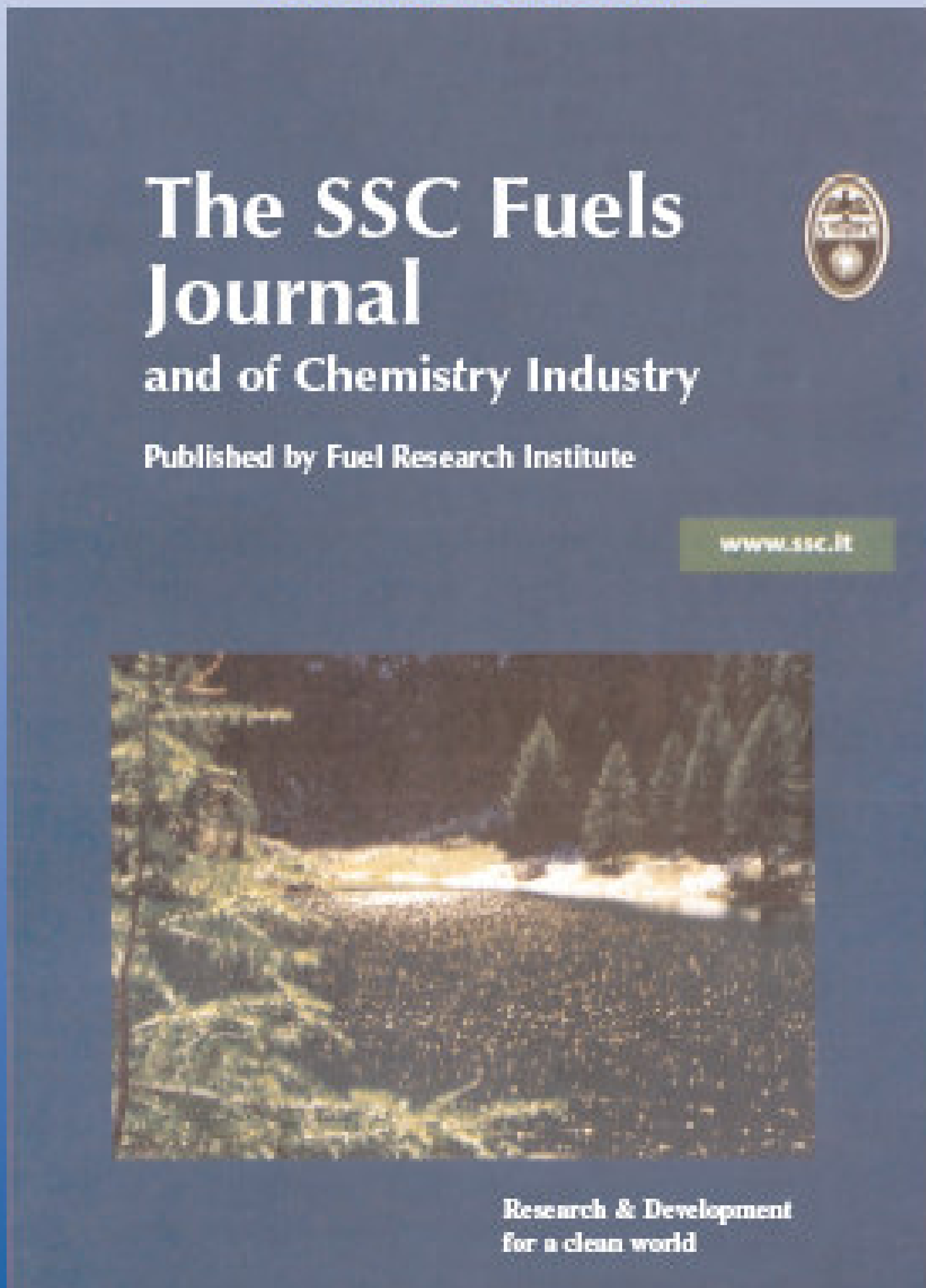
"GREENHOUSE GASES IN THE LIFE CYCLE OF FOSSIL FUELS: CRITICAL POINTS IN THE ASSESSMENT OF PRE-COMBUSTION EMISSIONS AND REPERCUSSIONS ON THEIR COMPLETE LIFE CYCLE"



INTERNATIONAL ASSOCIATION OF COAL OPERATORS

GREENHOUSE GASES IN THE LIFE CYCLE OF FOSSIL FUELS:
CRITICAL POINTS IN THE ASSESSMENT OF PRE-COMBUSTION EMISSIONS
AND REPERCUSSIONS ON THE COMPLETE LIFE CYCLE

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SUMMARY[1]

A previous Life Cycle Assessment on power generation via fossil fuels showed the weak points for coal, oil and gas in the combustion step.
The attention is now focused on the upstream segment of natural gas and coal. The results show the extent of upstream greenhouse gases emissions, their impact on the overall cycle and the uncertainty in emissions estimate which is largely a function of the site-specific sources of the upstream step and of the estimation methodology.
In the light of the environmental and economic implications of the Kyoto Protocol (and of the global market for greenhouse gas emission permits), standardized procedures and guidance are needed in order to develop complete and accurate emissions inventories.

KEYWORDS: *life cycle assessment, fossil fuels, power generation, upstream, greenhouse gases, emissions*

[1] This text summarises some of the results obtained from a study approved by contributing sectors and funded by the Ministry of Productive Activities and the Fuels Experimental Station in 2002-2003.

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1 Introduction

A preliminary assessment of the life cycle of fossil fuels in the production of thermoelectric energy [1] mainly analysed those aspects linked to the combustion phase, which constitutes the most relevant source of greenhouse gas.

In the above mentioned study, the fuels-energy-environment system was intentionally restricted to our domestic geographic boundaries, which allowed to assess the immediate repercussions of the environmental impact of thermoelectric energy production in the Italian scenario.

We must however stress that the thermoelectric energy production, especially in a domestic scenario characterised by a huge import of energy sources from abroad, has a wide range of repercussions in terms of greenhouse gas emissions. In other words, the production of energy from fossil fuels means the release of emissions also in the countries of origin of imported energy sources.

Therefore this issue takes a by far wider connotation, whose global scope was, however, the *driving force* that activated international agreements on climate changes, Kyoto commitments and the reduction measures foreseen by that protocol. And since the agreements on climate changes explicitly involve commitments aiming at prevention, control and mitigation of the consequences of man's activities at planetary level, also the assessment of the life cycle for the production of thermoelectric energy from fossil fuels must be faced in the light of this global context.

Due to its complex nature, this issue cannot be analysed in an exhaustive way. This essay will just outline the problems involved in the pre-combustion of fossil fuels and will focus on those elements that can have a significant impact on the total life cycle, and, by consequence, the "calculation" of greenhouse gas emissions foreseen by Kyoto protocol.

The points to be analysed in detail are:

- extent, level of uncertainty in assessment, and specificity of greenhouse gas emissions in pre-combustion;
- impact of these factors on the total life cycle for thermoelectric energy production.

2. Assessment of emissions in the two phases of the life cycle

Greenhouse emissions generated during pre-combustion (CO2 in particular) constitute the most significant part of total emissions. The reliability of this assessment is quite good: if we analyse this factor in our domestic scenario, for instance, the assessment can be obtained starting from a relatively small number of reliable quantities (content of carbon in fuel, heat-producing power) and parameters (consumption of each fuel and net production of electric energy) that can be found in official national sources (MAP, GRTN).

The assessment of emissions in pre-combustion is rather more complex, since it requires detailed information on each sub-step of the fragmented *upstream* of fossil fuels (mining, processing, transport/distribution).

For instance, oil and gas (often found together in deposits) have a segment of mining and processing described in Figure 1, which foresees a series of operation aiming at elimination the unwanted components.

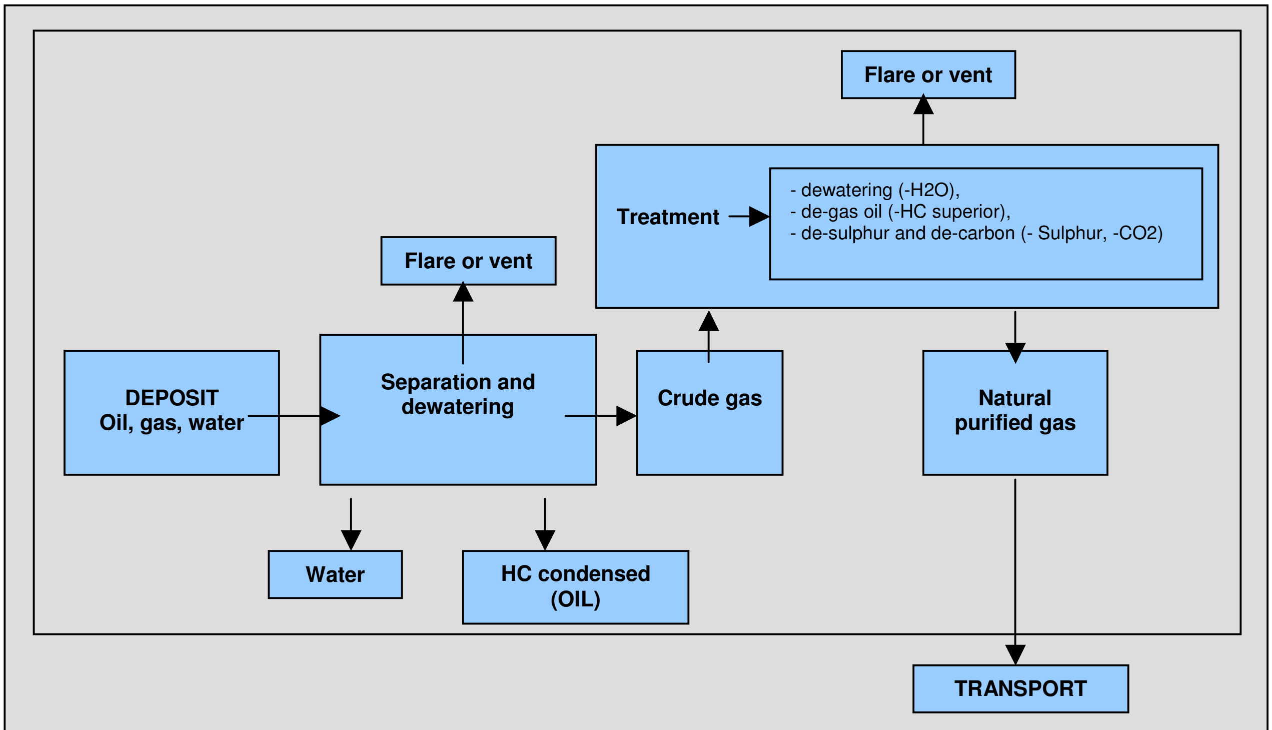


FIGURE 1: production and processing of natural gas

Greenhouse gases (mainly CH_4 and CO_2) released in the atmosphere after this processing, are released through “venting” and “flaring” (see Figure 2), during routine operation, maintenance interventions, and/or accidental events [2,3]. These emissions (generally defined as *fugitive emissions*) are formed by gases that cannot be stocked or used in another way. Venting and flaring constitute ordinary operation in the production of fossil fuels and are often unavoidable for safety reasons: these interventions, in fact, allow to reduce the risk of fire and explosion.

FIGURE 2: fossil fuels pre-combustion: greenhouse gas emissions

The upstream sector of fossil fuels (production, processing, transport and distribution) is a rather important source of greenhouse gas, mainly CH_4 and CO_2. In 1990, this sector contributed for about 20% of total methane emissions in UE (6).

In total, these emissions are defined "fugitive emissions", a definition that includes gases voluntarily (often for safety reasons) or involuntary (accidentally) released during production, processing and transport of fuels and in non-productive combustion. In the **oil & gas** sector, emissions are released in the different industrial sectors (production and processing on the field, transport/distribution) due to the characteristics of the sector at hand; gas, before reaching the final user, is transported through pipelines, valves, high pressure systems, devices and equipment. In the production/processing sector, emissions can come from routine operations, maintenance interventions, system upsets (of which the most common is the sudden opening of regulation valves caused by an unexpected pressure increase) or accidental leakage. Similar leakage due to compression or breaking of pipeline can occur also in the transport/distribution sector, which include stocking. During the production, the greatest source is linked to routine operation, mainly venting and flaring (i.e the release in the atmosphere of gas that cannot be separated or seized in any other way), gas release from processing venting, pneumatic means, safety systems etc.

Flaring is a controlled combustion (non-productive). Usually, separated gases are burned in torch. Emissions from flaring are therefore made manly of H_2O and CO_2 (combustion efficiency in flaring systems is generally very high). **Venting** is the release of unburned gases in the atmosphere, release often aiming at guaranteeing safety conditions during operations or linked to some peculiar processing operations. Operations that can cause venting include, for instance, the stripping of gases from glycol regeneration plants (used for the dewatering) or ammine regeneration (used in sweet and sour gas processing, rich in H_2S). From a qualitative point of view, venting emissions include CH_4, CO_2, volatile organic compounds (VOC), sulphur compounds (mainly H_2S) and various gas impurities.

Venting gases can, in many cases, be burnt (flaring). In this way, hydrocarbons become oxidised to CO_2 (by partially reducing environmental impact in terms of greenhouse gas, since CO_2 has a greenhouse effect 21 time lower than that of methane over 100 years). Venting is the most used option also when there are relevant quantities of inert gases (ex: CO_2, N_2), i.e. when flaring cannot be used because gas is burning with difficulty. Technically speaking, emission reduction from venting and flaring can be implemented through either preventive measures (improving controls and maintenance of plants, lines etc.) or injecting gases in the deposit, a solution that allows to increase production yield (EOR). Due to geologic or geographic conditions of deposit, EOR is not always possible. Gases rich in hydrocarbons can be recovered to produce energy on the field.

In the sector of **solid fuels**, emissions, mainly formed by methane, are released during production. The amount released in post-mining is about 1/5 of that produced in mining (for underground seams) and about 1/4 (for open-air seams). Methane (present in concentration at around 90% together with other gas compounds formed during carbogenesys) is seized in carbon seams in more or less relevant quantities according to the deposit and the type of coal. This phenomenon is more relevant for underground seams, in which gas, seized through absorption in the pores of the structure, is kept there by pressure from upper strata. During mining, part of the gas is spontaneously released because of cracks produced. The gas in the deposit, however, must be removed mainly for safety reasons: the air-methane ignition limit ranges between 5 and 15% vol/vol of methane at 20°C.

Generally, the removal of gas can be made either by forced ventilation or by degasification systems often installed before mining. In the former case, the gas produced is burned (flared) or released in the atmosphere (since the methane present is highly diluted); in the latter case, a gas rich in methane is produced and can be used as energy source at the place of production or - if there are the needed infrastructures - transported via pipelines and sold. The cost-effectiveness of methane recovery depend on many factors, including the quantity present in the deposit, its purity and the geologic conditions of the deposit, which can affect a possible use of recovery technologies.

The amount of emissions from *flaring e venting*, though reduced if compared to emissions from combustion produced in the energy sector (Figure 3 [4]) and other economic macro-sectors (transports in particular), is not negligible.

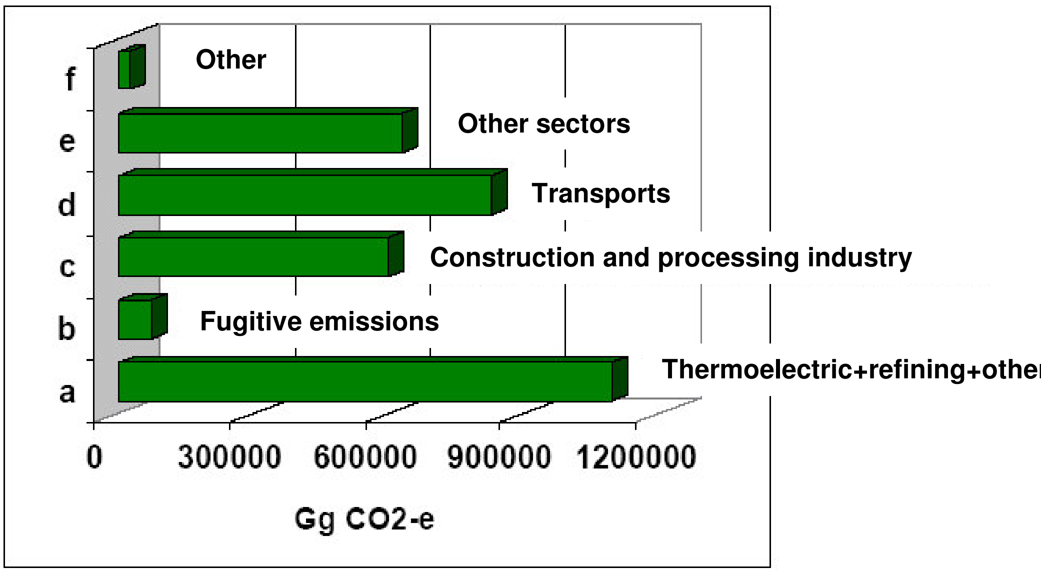


Figure 3: Distribution of European greenhouse emissions in energy sub-sectors.

According to global evaluations [5], losses due to venting and flaring in the European production of natural gas in 2000 are about 3 billions of m3 of natural gas (about 1% of European gross production) and in terms of greenhouse emissions are equal to about 50 million tons of CO_2, which in turn are equal to 15% of the Kyoto global reduction commitment for Europe within 2010 (about 340 million tons). As concerns coal, in 1997 European emissions of methane linked to the mining are assessed at about 39 million tons of CO_2-equivalent [6].

The burdensome economic commitments deriving from the agreements on climate changes are moving attention on *upstream* emissions, too. In fact, more and more numerous are the initiatives to assess in a more accurate way and to limit emissions from *flaring* and *venting* through preventive actions (realized by optimization of routine operations, improvement of plant maintenance, pneumatic systems, pipelines etc.), the recovery and re-usage of these gases as energy source (in case of hydrocarbon-rich gases), as well as the re-introduction of gases in the deposits, which allows also to increase production yields or produce oil non-recoverable in another way (through Enhance Oil Recovery, EOR). In the USA, about 30 million tons/year of CO_2 are injected in wells considered at the end of their economically productive life cycle, and this generates an increase - via EOR- of about 10-15% in the mining yield of oil [7,8].

Also in Italy initiative are underway to zero the contribution - though modest at national level - of these emissions (*zero gas flaring* [9]).

At European level, the most significant case is Norway (explained here below) where since 1996 about 1 million tons/year of CO_2 - separated from gas extracted from the Sleipner Vest deposit - are sequestrated in a deep saline aquifer reserve.

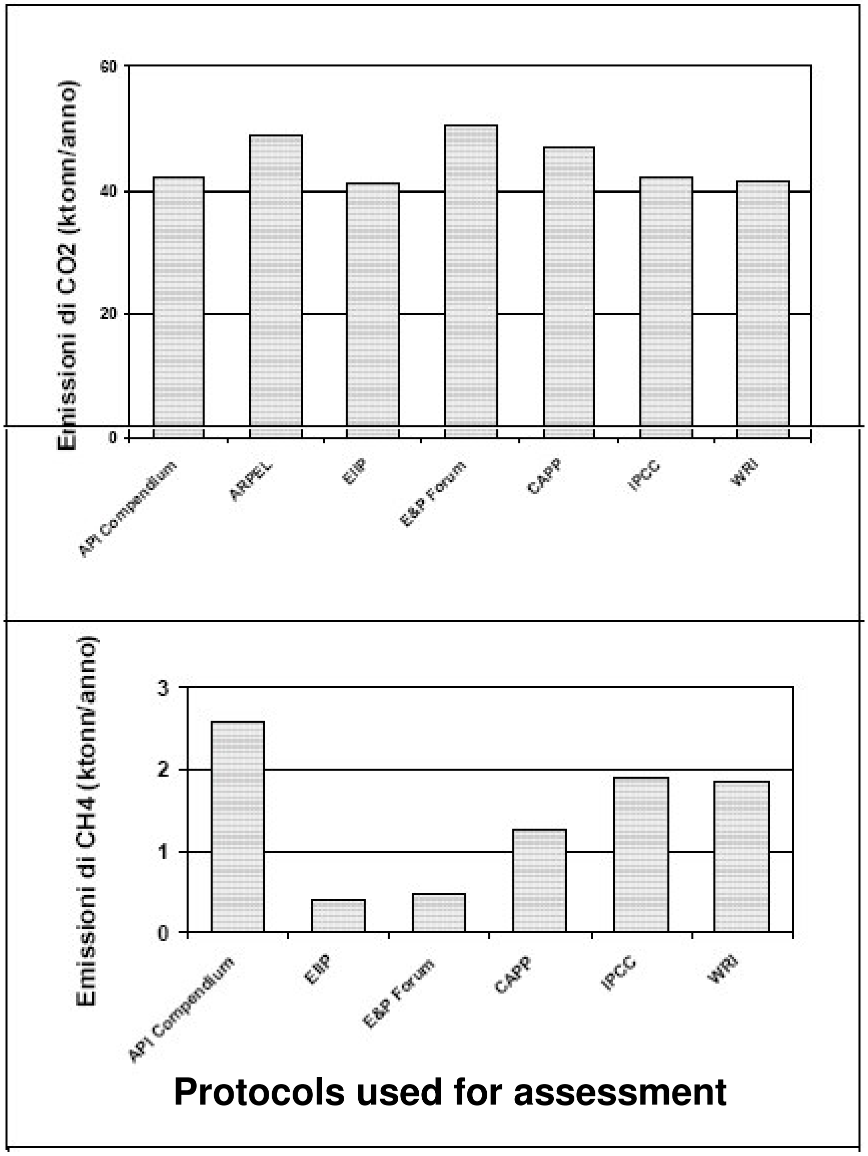


Figure 4: Comparison between results obtained by applying different protocols in the assessment of CO2 and CH4 emissions from onshore oil and gas wells

It must be however said that world estimates cannot currently guarantee the exhaustiveness of collected data and the accuracy of the evaluation, in particular for developing countries and former Soviet Union [10-12]. This is due to the extent of sectors involved as well as the complex nature and the site-specificity of many operations carried out on the deposit in the mining/processing phase, operations linked to the specific processing choices of each company and the efficiency of systems installed to reduce emissions as well as the gas composition for that specific deposit and its geographic location, which can have an impact on the creation of relevant needed infrastructures. location, which can have an impact on the creation of relevant needed infrastructures.

And last but not least, the uncertainty of evaluation is linked to the different procedures used to make the evaluation. Just to give an example, Figure 4 shows the comparable data of CO_2 and CH_4 emissions in the extraction of oil and gas obtained according to the protocols proposed by different organisations [13].

To support the oil and gas industry in assessing the entire production cycle (from extraction to marketing) and make available some reliable information on sources, quantities and composition of greenhouse emissions generated by the different sectors, the American Petroleum Institute (API) has recently worked out a series of guidelines [14] to provide a possible harmonisation methodology for the different evaluation approaches and guarantee a common base for data comparison.

This document is also proposed as reference for national and international organisations that are building or revising protocols for the drawing up of official national inventories of emissions, inventories that for the time being form the database to calculate greenhouse emissions.

IPCC Guidelines and national inventories of emissions

IPCC (Intergovernmental Panel for Climate Change) Guidelines are among the documents produced in the framework of the UN Frame Convention on Climate Change UNFCC (signed by UN member countries during the World Conference on Development and the Environment - Rio de Janeiro 1992). According to this Convention, signatory countries committed themselves to adopt programmes and measures aiming at preventing, controlling and mitigating the effects of anthropogenic activities on the planet.

IPCC, established in 1988 by the World Meteorological Organization (WMO) and by the United Nations Environmental Programme (UNEP) is the organisation entrusted with the drafting of guidelines to build up emission inventories and monitor the evolution of the situation.

A body called "Conference of Parties" (COP) has been established within the Frame Convention, and it is tasked with the implementation of the general commitments contained in the Convention. According to the agreements among signatory countries of UNFCC, EU countries forward the assessment of national emissions obtained in compliance with IPCC methodology.

The first national inventories, started by ENEA, is presently assigned to APAT, the institutional referent of the Ministry of the Environment and the European Environmental Agency (EEA).

The first IPCC guidelines were developed in 1990 in collaboration with IPCC, OECD (Organization for Economic Co-operation and Development) and IEA (International Energy Agency) and published in 1995 after a revision involving world-level experts.

IPCC guidelines provide a step-by-step methodology to calculate greenhouse emissions (CO2, CH4, N2O) and other compounds (Nox, CO, NMVOC, SO2) from the following anthropogenic activities:

- Energy
- Industrial processes
- Solvents and other product use
- Agriculture
- Land use Change and Forestry
- Waste

Guidelines were subsequently revised (1996) and integrated by "IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" reports of June 2001.

Figure 5 - IPCC Guidelines and national inventories of emissions

In fact, also IPCC (see Figure 5), in two documents [15,16], published to complete the "Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories" [17], acknowledges that it is difficult to calculate the emissions in an accurate way, points out some deficiencies of the 1996 Guidelines and gives recommendations on the methodology to be followed.

In relation to upstream emissions, the IPCC guidelines of 1996 focussed their attention, among other things, on methane emissions only. However, in these guidelines greatest attention at world level was paid to the possible recovery of this gas during its extraction (mainly to exploit its heating power and also for safety reasons) as well as during its transport/distribution to avoid leaks [18,19].

The wide fluctuation range of estimates for pre-combustion methane emissions is clear in Figure 6, which shows emissions for the oil and gas sector (total of extraction, processing, transport and distribution) and for the coal sector (mining and post-mining, both for open-air coal-mines and underground coal-pits) obtained following IPCC emission factors (Reference Approach, [20]).

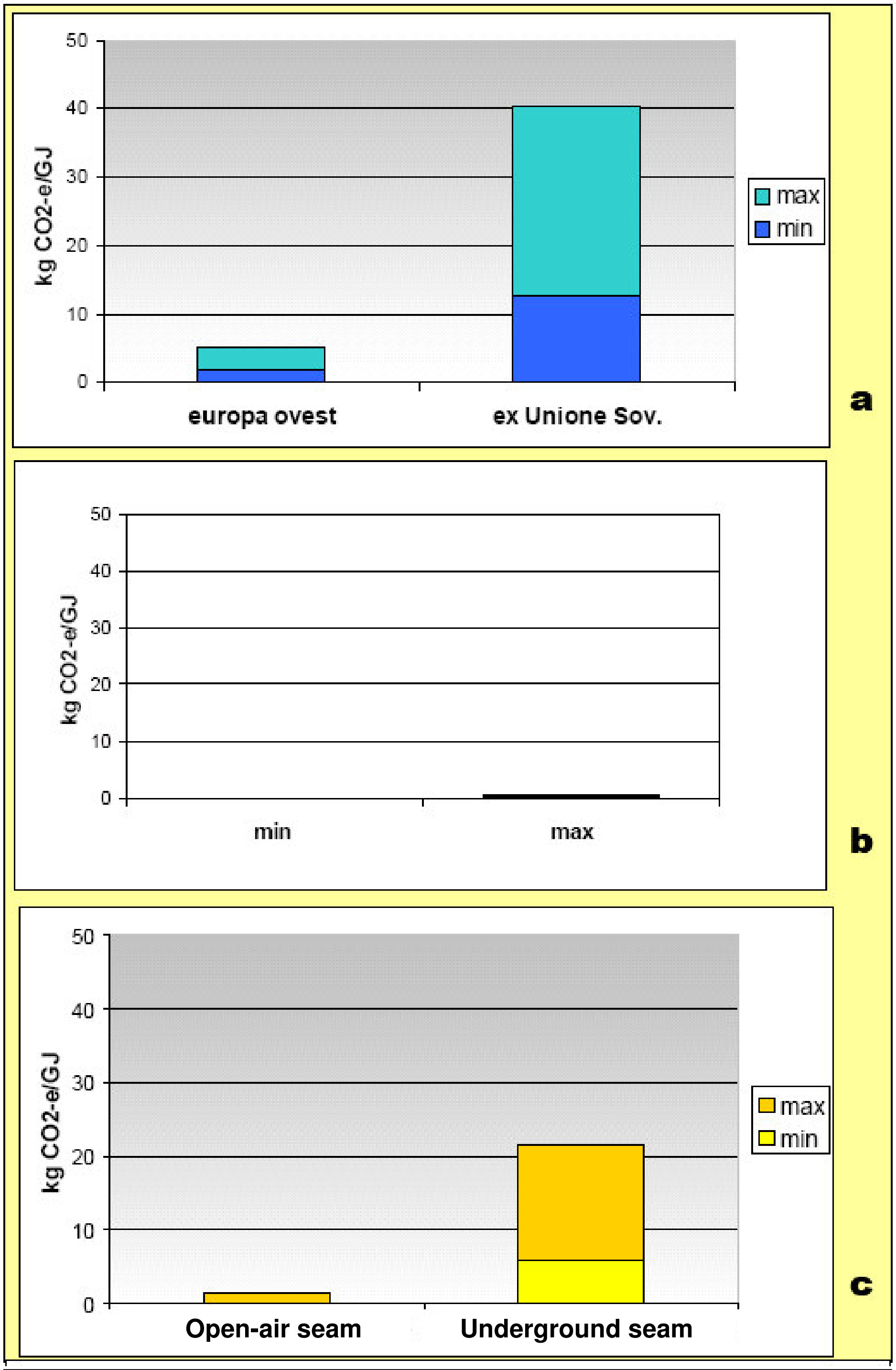


Figure 6 - Range of methane emissions in pre-combustion of: (a) natural gas; (b) oil; (c) coal; data are calculated according IPCC factors (reference approach).

The clear variability shown for the natural gas from former Soviet Union (Figure 6a) mirrors the poor reliability of Russian data stressed by many sources for quite a while [10-12] and assessed by Gazprom at 3 - 7% of gas produced, compared with a USA average of about 1.4+/-0.5%.

It is therefore clear that an improved evaluation approach is needed to improve data reliability on emissions.

3. Natural gas pre-combustion: greenhouse emissions

Among the site-specific factors for the oil and gas sector, IPCC lists the typology and efficiency of control/reduction systems and crude gas composition for that deposit, with particular attention to the CH_4/CO_2 relation. In fact the latter can have an impact on the amount of upstream emissions and on total emissions for the life cycle, as it is better explained here below.

There are deposits in which the CO_2 percentage in gas reaches even 20% of volume [21,22]. For some French, Australian, Japanese and Mexican wells, values are even higher [23]. Moreover, it seems that the presence of high CO_2 concentrations cannot be correlated with other specific physic parameters of that deposit.

It must be said that if the content of CO_2 and/or other polluters - H_2S in particular - is very high, the cost of cleaning treatments would be excessive and therefore it is generally preferred to leave the gas "in situ" [24].

From an environmental point of view, the problem arises when the CO_2 - extracted from the deposit together with the natural gas and separated from the latter to transform the gas according to market specification - is released into the atmosphere (vented) following current practices [2,7,8,14,25,26]**.** The maximum CO_2 content admitted for pipeline transport, in fact, is a limit imposed by several countries and is about 2% (vol/vol).

In conclusion, the CO_2 already present in gas at the deposit, if released in the atmosphere, increases pre-combustion and total emissions.

This increase, of course, depends on the composition of crude gas: in specific cases, this contribution can be substantial.

On this matter, it is worth to mention the case of Norway, where the Statoil has realised the first large-scale project for the re-injection of the CO_2 extracted with natural gas from the Sleipner Vest deposit (one of the largest reserves of natural gas in the Northern Sea) on the base of economic repercussions deriving from the commitments taken on greenhouse emissions reduction. The gas of this deposit, in fact, contains up to 9% of CO_2 that must be reduced to 2,5% in order to transform the gas according to export specifications. Usually, the separated CO_2 was released in the atmosphere and increased total Norwegian emissions by about 3%. The Norwegian government then decided to levy a carbon tax on anthropogenic emissions in oil and gas production and this pushed the oil company to invest in the Sleipner project, thanks to which the CO_2, after separation from extracted gas, is re-injected (sequestrated) in a deep saline aquifer reserve (Utsira) located in the Norwegian zone of the Northern Sea. The investment costs were recovered in about 1½ years [27].

This project is followed with interest at international level since it allows to verify "on the spot" the stability of geologic sequestration of CO_2 in deep aquifers, a technical solution that could be determinant to sequestrate CO_2 emissions produced during combustion. Many are the studies and initiatives underway in this direction [8,28].

The Sleipner project is one of the clearer demonstration of economic repercussions of greenhouse emissions (including extraction ones) in the light of agreements on climate changes.

To provide a quantitative assessment of upstream emissions, their uncertainty and the impact of some specific site factors, we here below compare some data on pre-combustion emissions of natural gas in different countries.

3.1. Australian Gas

Figure 7 shows the final data of a study made by the Australian Coal Industry [29] on pre-combustion emissions of Australian natural gas.

Crude gas has CO2 content ranging from about 2% and 16 % vol/vol, according to the deposit.

In the worst case (CO2 at 16%), about 50% of pre-combustion emissions are due to the CO2 of the deposit released in the atmosphere. Total pre-combustion emissions (CH4+CO2) range between 8 and 17 Kg CO2-e /GJ, in relation, respectively, to the minimum and maximum content of CO2 (Figure 7).

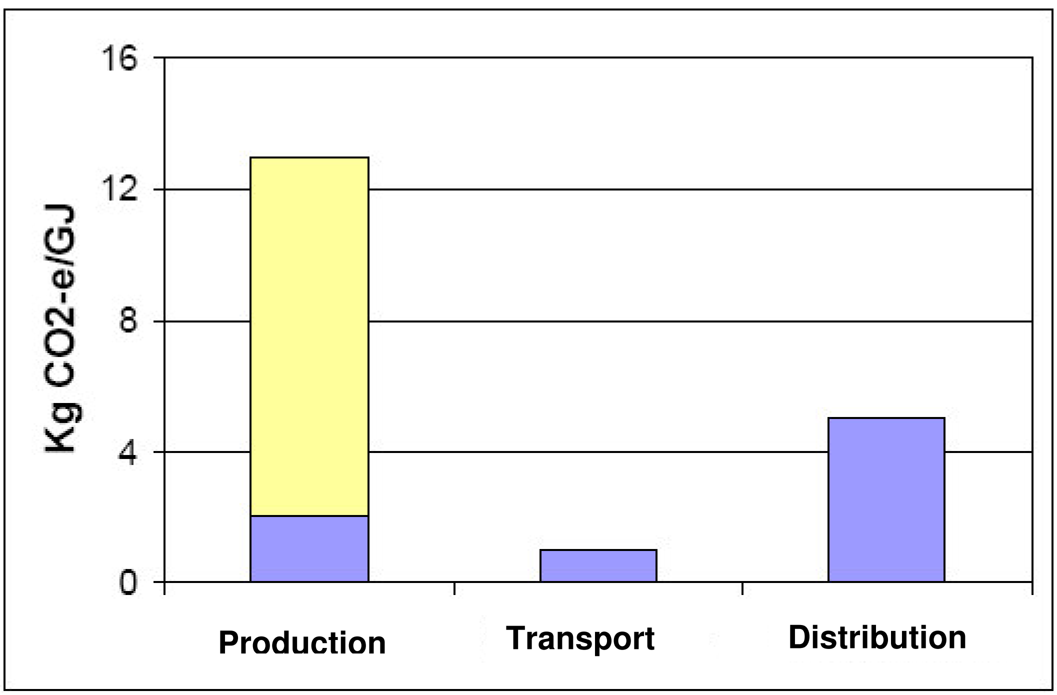


Figure 7: Greenhouse emissions in pre-combustion of Australian natural gas. The range of production segment mirrors the minimum and maximum CO2 content of the gas in the deposit (from Ref.29)

3.2. Italian Gas

Analysing the data published by the Italian gas industry [30] (showing 1995 disaggregated data for the different sectors), total pre-combustion greenhouse emissions (CH_4+CO_2) would be 6.4 KgCO2-e/GJ, divided as follows: 0.9, for extraction; 0.7, for transport; 4.8, for distribution. CO2 emissions are mainly linked to the production/processing sector (flaring); whereas CH4 emissions are mainly due to the "transport/distribution" sector. Specific pre-combustion emissions of domestic gas are therefore below the Australian ones, even as concerns the minimum CO2 content of crude gas.

What stated above means that the *upstream* of the Italian gas industry is characterised by a good efficiency of control systems and that the Italian gas presently extracted is characterised by a low CO2 content.

3.3. Imported Gas

Italy has a strong dependence on foreign imports. It imports about 60% of consumed natural gas from Russia and Algeria and this gas is characterised by an average-high content of CO2 at the level of deposit (about 6% for the Algerian gas and up to 20% for the Russian gas [29]).

From literature we see that upstream emissions of Russian gas would range between about 20 - 44 Kg CO2-e circa for GJ of extracted gas.

As concerns Algerian gas (if we assume an average CO2 content of 6% in deposit), pre-combustion emissions would be about 13 Kg CO2-e/GJ.

A comparison of data concerning Australian, Italian, Russian and Algerian pre-combustion emissions from natural gas are shown in Figure 8.

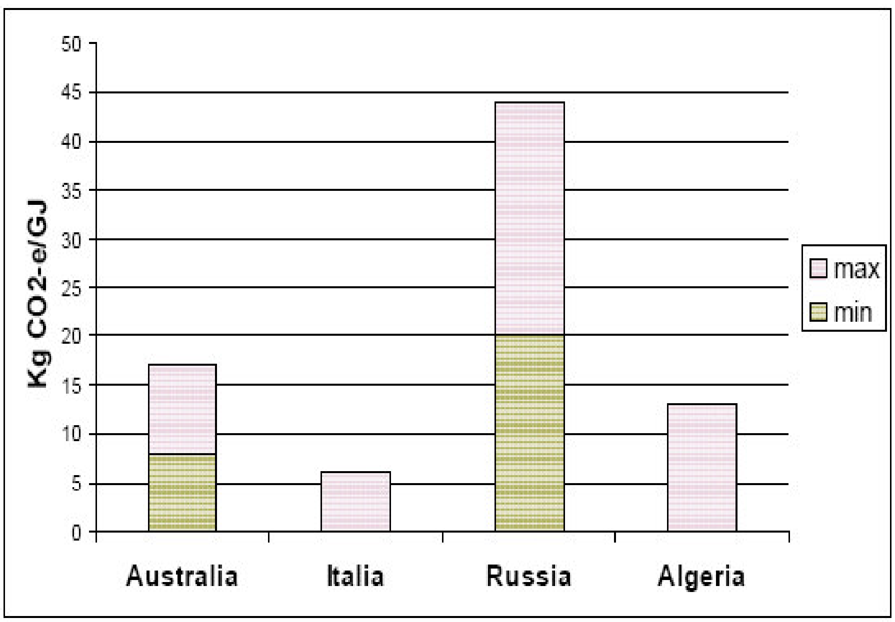


Figure 8: Greenhouse emissions in pre-combustion of natural gas produced in different countries and characterised by different percentage of CO2 in gas in deposit (see text)

4. Coal pre-combustion sector: greenhouse emissions

Greenhouse emissions in coal pre-combustion are mainly formed by methane (main by-product of gas in coal seams) generated during the carbogenesys together with more modest quantities of CO_2, H_2O, hydrocarbons and inert gases present in different proportions according to the degree of evolution of this process (see Figure 2).

According to specific geologic and geographic situations, the gas present in the deposit can be released in the atmosphere (vented), burned (flared) - and in this case emissions are mainly made of CO_2 - or recovered [3,6,18].

When the gas is released as such in the atmosphere, the amount of emissions (methane) per energy unit of extracted coal generally depends on the quality of coal and is higher in coal from underground seams as shown in Figure 6c, which clearly shows the wide range of variation of estimations based on IPCC average emission factors. By the way, about 90 % of coal world production comes from underground seams (about 50%) and open-air mines (about 40%) according to data of 1990 [15].

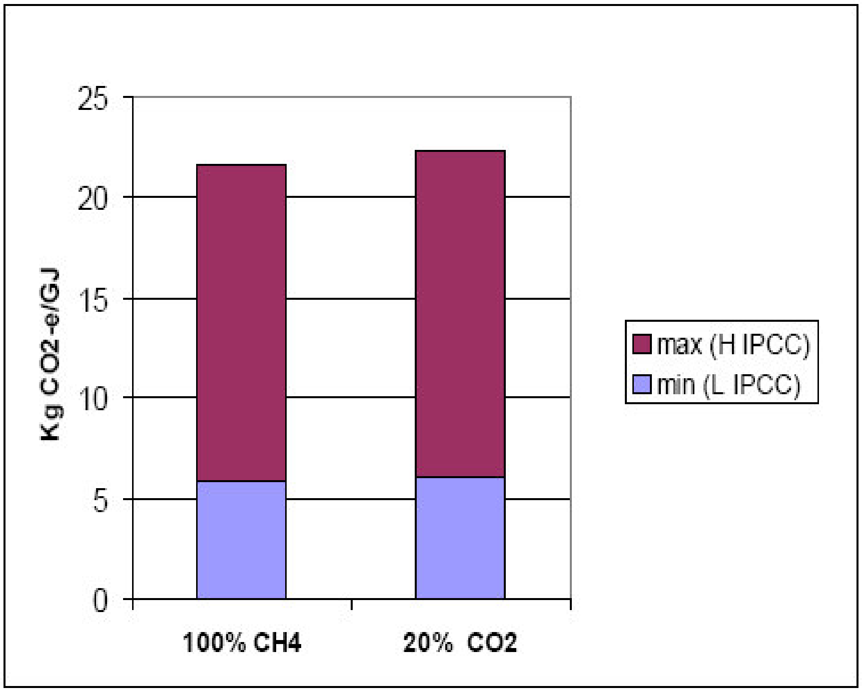
As concerns CO_2 in gas deposit, the problem is qualitatively similar to that of natural gas. In fact, also in the case of coal, there are seams (in Australia, France and Poland for instance) in which gas is rich in CO_2 [3], which was produced by a different evolution process [31].

Like natural gas, we can estimate the amount of pre-combustion emissions also for coal.

The evaluation shown here below takes into account the worst case: we supposed the mining of coal from underground seam (which causes the maximum release of methane, see Figure 6) and used "low" (L) and "high" (H) methane emissions, respectively (IPCC Guidelines[20]), for two different CO_2 contents (0 and 20%).

This calculation includes methane emissions due to *post-mining* (i.e. the transport of coal from the mine to the using place) which however are less relevant than for the mining phase (Figure 6c and explanation of Figure 2).

Pre-combustion greenhouse emissions per energy unit of mined coal are shown in Figure 9.



It is clear that the increase linked to the presence of CO_2 in the gas is modest if compared to the presence of methane only (at equal amount of energy produced), as it could be envisaged since the methane has an heating power 21 times higher than that of CO_2 (over a time span of 100 years).

Figure 9: Range of greenhouse emissions in pre-combustion of coal mined from underground seam according to different percentages of CO2 of the gas in deposit

5. Incidence of pre-combustion emissions on complete fuel cycle of natural gas and coal for thermoelectric energy production

5.1. Natural Gas

To assess the incidence of upstream emissions in the complete life cycle for thermoelectric energy production, let's suppose to use the different gases shown in Figure 8 to produce energy by fuelling a gas-turbine combined cycle plant (NGCC) with an efficiency of 54% (*Best Avaliable Technology).*

The comparison is graphically shown in Figure 10a. The assessment was obtained from pre-combustion data shown in Figure 8, with a contribution of 380 gCO2/kWh for the combustion phase, on the efficiency of relevant plant (Figure 7 of reference [1]).

It is clear that, if we consider the complete life cycle, upstream greenhouse emissions of Algerian gas and, even more, Russian gas give a higher contribution to total greenhouse emission than the gas produced and used in Italy. In the case of Russian gas, in particular, even using the best available technology, emissions can reach about 670 g CO2-e/kWh, with an increase of about 60% if compared to gas produced and used in Italy.

As concerns the variability of estimations, it must be said that in the case of Russian gas, for instance, data can be also expressed as 380 (from combustion) + 210 (pre-combustion average)+/- 80 g CO2-e/kWh, where the interval of variation has been calculated as mean of minimum and maximum values shown in Figure 10a.

It must however be stressed that efficiency of combustion technology is one of the most important factors to reduce emissions. In fact, if the above data are compared with the average yield of gas plants in 1999, equal to 43% [1], we obtain the result shown in Figure 10b. Therefore the huge increase of efficiency of new combined cycle plants (NGCC) allows to reduce consistently greenhouse emissions: in the worst case (Russian gas at 20% of CO_2 in deposit), using NGCC technology with a yield of 54% (Figure 10 a) we obtain a drop in greenhouse emissions in gas life cycle equal to about 170 g CO_2-e/kWh, 20% less for each kWh produced if compared with average emissions of gas plants in 1999.

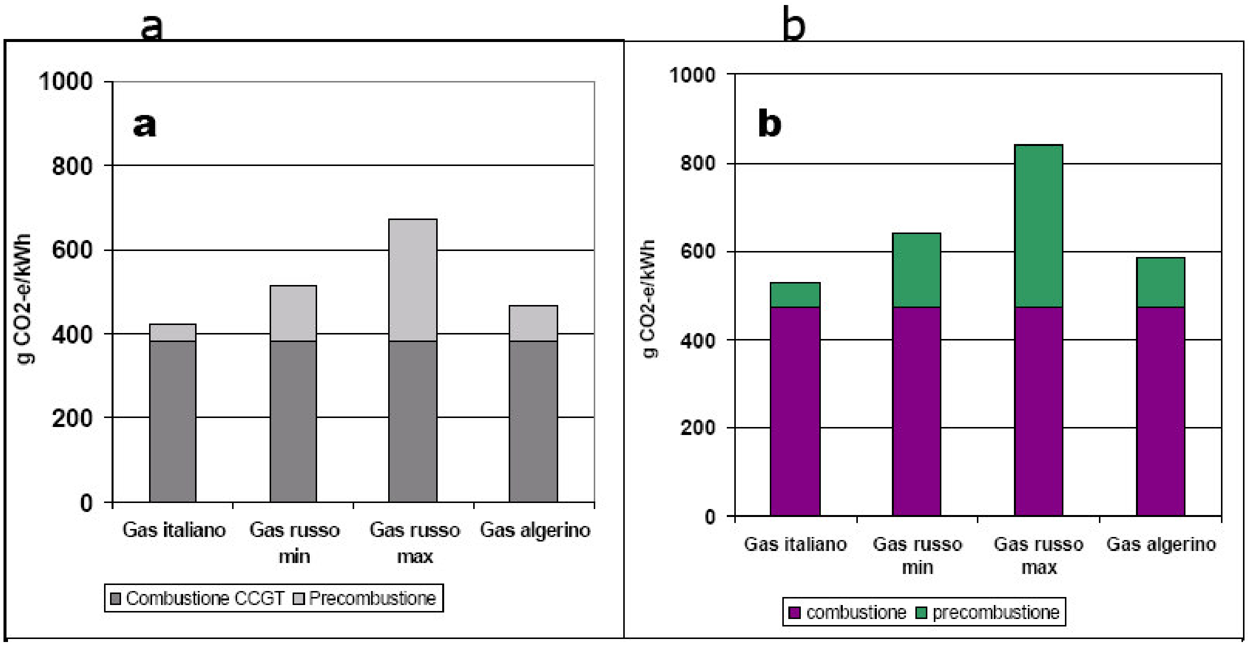


Figure 10: Life cycle of national and imported natural gas and greenhouse emissions in thermoelectric production: (a) NGCC plant, yield 54%; (b) average of gas-fuelled plants in Italy 1999, yield 43%; (Source: data from Figure 8)

5.2. Coal

Just as we have done for natural gas, let us now consider greenhouse emissions in the complete life cycle of coal for thermoelectric use, while supposing to use coal from underground seams (the two cases of Figure 9) to produce energy by fuelling a “Ultra Super Critic” (USC) plant with a yield of 44%. Results are shown in Figure 11a and 11b.

It comes out, therefore, that in the worst case (coal from underground seam) in presence of a gas in the seam (methane only or methane with 20% of CO_2) greenhouse emissions in the complete life cycle of coal range between 830 and 910 (gCO_2equiv/kWh), of which about 780 from combustion.

A similar assessment in the case of coal from an open-air seam (where pre-combustion emission are reduced, Figure 6c) gives total emissions ranging from 780 and 790 g CO2-e/kWh.

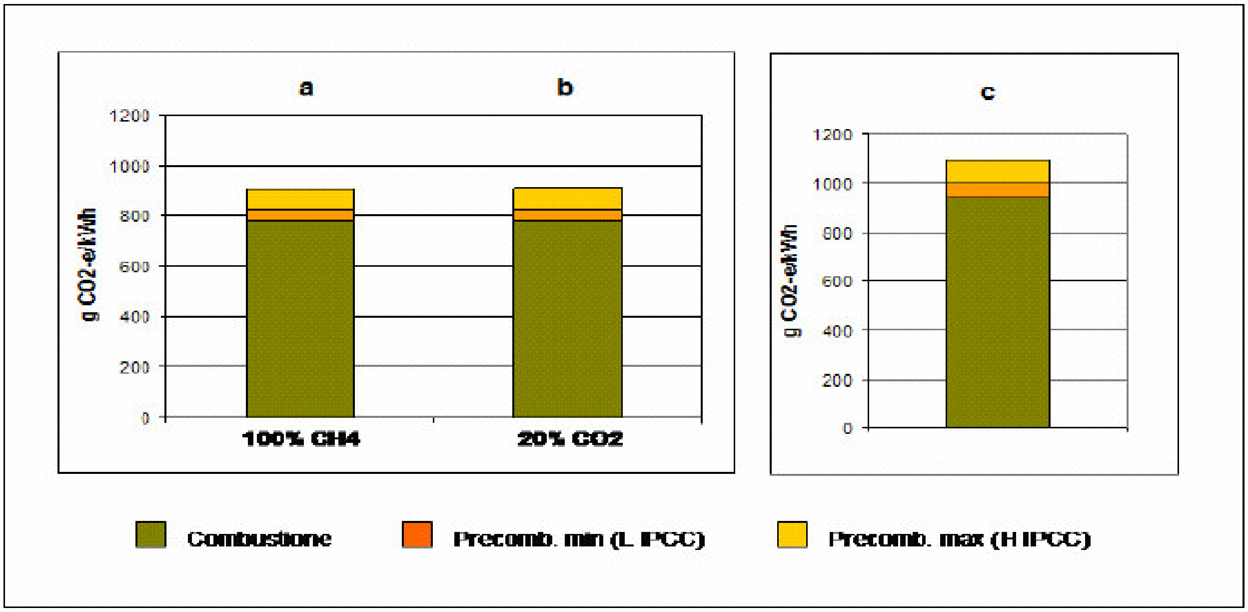


Figure 11: Greenhouse emissions in the life cycle of coal mined from underground seam and used to produce thermoelectric energy. (a) and (b): USC plant (yield 44%) for the two cases in Figure 9; © average for coal plants in Italy in 1999 (yield 36%).

However, as in the case of gas, efficient combustion technologies have a vital role in reducing emissions also in the case of coal. In fact, if we compare data from Figure 11a (USC, yiel of 44%) and those of Figure 11c calculated on the base of an average yield of coal-fuelled plants in 1999 (equal to 36% [1]), we note that USC can realise a drop in greenhouse emissions of about 190 g CO2-e/kWh, equal to 17% less per each kWh produced with reference to coal-fuelled plants in 1999[2].

5.3. Comparison between borderline cases for gas and coal

If we compare the complete life cycle of natural gas and coal (Figure 10a and 11 a,b) by using the best technologies available to produce energy, total greenhouse emissions amount to about 670 g CO2-e/kWh for natural gas (worst case: import from Russia, with 20% of CO2 in gas in the deposit) and to about 910 for coal (worst case: coal from underground seam), showing a ratio of 1:1,3 between greenhouse emissions [natural gas/coal].

[2] *By the way, according to ENEL, the plant of Torre Valdaliga Nord (Civitavecchia) that uses Super Critic Technology will have a yield of 45% (Staffetta Quotidiana, 2 December 2003)*

It is clear that, if compared to natural gas produced and used in Italy, import gas can involve a great increase in terms of greenhouse gases.

To conclude, the data shown above stress that the range of variability in greenhouse emissions in the life cycle, at the same amount of energy produced, is that of Figure 12, which consider a NGCC plant for natural gas (yield of 54%) and a USC plant for coal (yield 44%). Both cases show combustion emissions and pre-combustion emissions: in the case of natural gas, graph (a) refers to gas produced and used in Italy; graph (b) shows the borderline case of Russian gas (for which the maximum value found in pre-combustion takes into account a 20% content of CO2 in deposit [29]). As concerns coal, graph (a) shows pre-combustion emissions of fuel from open-air seam and graph (b) those of coal from underground seam (minimum and maximum).

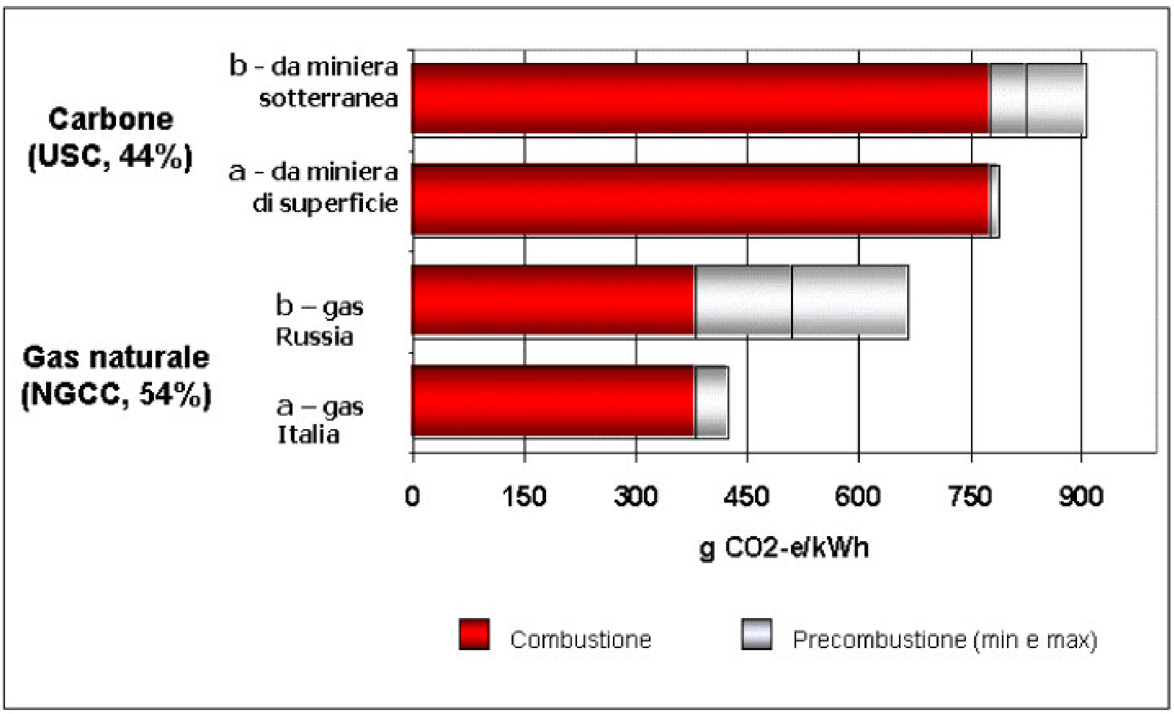


Figure 12 - Potential variability range of greenhouse emissions in the life cycle of natural gas (NGCC, yield 55%) and coal (USC, yield 44%) for borderline cases (worst and best) obtained from data presented in this text. In the case of Russian gas, the maximum value of the pre-combustion sector takes into account the contribution of CO2 of the gas in deposit (envisaged at about 20% CO2 content (29)).

***Legend*:**

natural gas: a) gas produced and used in Italy; b) borderline case of imported Russian gas (see text).

As final consideration, it is worth saying that if the examples shown above clearly demonstrate that the amount of pre-combustion emissions can be relevant, the above reiterated variability of data causes the problem of accuracy for these same data, a factor that has a great importance in the light of the global scenario outlined by Kyoto agreements. These latter introduce two key factors as influenced by data reliability: permits/credits of emission and their cost, which at present is around $ 40/ton of CO_2 [32].

6. Conclusions

Data presented show some critical elements in pre-combustion of fossil fuels to produce energy, which, besides an impact on complete life cycle, can have concrete repercussions on transaction mechanisms of emissions foreseen in Kyoto agreements.

These aspects can be summarised as follows:

- pre-combustion greenhouse emissions (mainly made by CH_4 and CO_2) can be a good amount of emissions in a complete life cycle. Sources and size of these emissions, especially in extraction/production phases, are greatly site-specific: in fact, they depend on the specific processing and treatment chosen for that wells/deposit and on the different practices used (flaring and venting), the efficiency of reduction/control systems, the infrastructures, the specific composition of crude gas (CO_2/CH_4) present in the seam, as well as the procedures used to calculate them;
- the assessment of these emissions obtained from average emissions factors can therefore be subject to a more or less relevant degree of uncertainty. This factor is acknowledged also by IPCC, the official body appointed by UNFCCC to draft guidelines for the realisation of *national emissions inventories*, which presently contain the official data of "calculation" of emissions for the about 150 signatory countries of the convention on climate changes and constitute the point of reference to monitor their evolution;
- in the life cycle, the assessment of emissions due to the production of thermoelectric energy must consider the efficiency of combustion technology used, a factor that has a key role in emission reduction. In other words, also data on specific pre-combustion emissions must be related to the net energy produced and the technology used.

  Just to exemplify, in the borderline case of Russian gas (which represents about 30% of our imports of natural gas), the estimation of pre-combustion greenhouse emissions ranges between about 32 +/- 12 Kg CO_2-equiv (i.e. about +/- 38 %) per GJ of gas produced. If we suppose to burn this gas using the best available technology (gas-turbine combined cycle with a yield of 54%), greenhouse emissions (pre-combustion+combustion) for gas imported from Russia would be about 590 +/- 80 (g CO_2-e/kWh), with reference to a value of about 420 in case of gas produced and used in Italy. Though stressing that the Russian case is a borderline one, the high interval of variability detected is due to the range of variability of IPCC factors and the potential contribution of CO_2 in gas at deposit (assessed at about 20% [29]), and this makes clear the need to have more reliable data to quantify pre-combustion emissions.

In the case of coal, the assessment of pre-combustion greenhouse emissions calculated using IPCC factors ranges between 1 and 16 Kg CO_2-equiv/GJ of mined coal (from open-air and underground seams respectively). If we burn this coal in a "Ultra Super Critic" plant (with a yield of 44%), greenhouse emissions would range between about 780 and 910 g CO_2-equiv/kWh, in the two borderline cases examined, of which about 780 would come from combustion.

The need for reliable data on emissions becomes even more important in the light of emission transaction mechanisms envisaged by Kyoto objectives to reduce emissions.

In fact the envisaged emission reduction involves a complex and burdensome national commitment which should be eased in the light of interventions foreseen in the CIPE deliberation of 2002 [33]. This provision, based on flexible mechanisms, offers incentives to companies to buy emission reduction credits by investing in advanced technologies (also) abroad, where the potentialities of interventions are higher (with definitely lower marginal costs) in comparison with the domestic situation that normally has average energy efficiency standards higher than the European average ones [34,35].

As concerns the *upstream sector*, in particular, the CIPE deliberation has clearly envisaged the possibility for the companies to acquire reduction credits through JI (Joint Implementation) and CDM (Clean Development Mechanism) projects "of *gas flaring* and *gas venting* in oil-digging wells", projects involving the so-called "Annex I" countries (Industrialised countries and economy transition countries, including Russia) and developing countries, respectively. The amount of carbon credits already defined by CIPE deliberation for these projects is equal to 12 Mt CO_2-eq. Another contribution, equal to 10-20 Mt CO_2-eq, is foreseen as additional measure.

Therefore good opportunities could come to companies from JI and CDM projects developed in the upstream sector [34] and a great contribution could come to the country to catch the Kyoto objectives in 2008-2010 (- 93 M.tonn CO_2-eq in total).

In parallel with economic relapses linked to Kyoto engagements and as guarantee to both companies investing in new technologies to realise these projects and public funds destined to boost these investments, it is necessary that data of emissions be reliable.

This clearly requires the adoption of harmonised national measure/control procedures which allow to receive certified emission data.

In other words, only if data are reliable can the system of exchange mechanisms work, and only then can we have a reasonably certainty of the real following of Kyoto protocol, whose costs would be de facto borne by the whole country.

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