Application of carbon capture and sequestration technologies on power generation plants located in South-West Sardinia

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Abstract

The increasing interest on the environmental protection and the implementation of Kyoto protocol are making more and more interesting the development of CCS technologies for their application in power generation processes. In particular, the presence in Italy of a large coal basin, located in the Sulcis area (South-West Sardinia), suggests the application of the ECBM (Enhanced Coal-Bed Methane) technology for CO_2 geological sequestration.

This paper reports a preliminary economic analysis on the introduction of CCS technologies at the power generation plants located and likely to be located in the Sulcis area. In particular, four plants have been considered: two existing coal-based pants, an existing tar-fuelled IGCC and an advanced coal-based ultrasupercritical plant which is expect to come into operation in 2012. The analysis considers an amine-based CO_2 capture system and the carbon sequestration through ECBM technology.

The analysis shows the convenience to invest in CCS systems for three of the four considered plants; the global profit and the pay-back time are strongly influenced by the cost of CO_2 emission licenses and the specific amount of extracted methane. In any case, the analysis show the need of a more detailed experimental study on the application of ECBM technology at the Sulcis coal basin, due to evaluate the main process parameters.

Introduction

In the Kyoto Protocol the Industrial Countries committed themselves to cut 5,2% off the greenhouse gas emission compared to those of 1990, before 2012. The commitment of reduction and limitation of greenhouse gas emission the Countries underwrote are indicated in the Kyoto Protocol, but every Country has different goals. In particular Italy applied to cut 6.5% off the emission.

For implementation of Kyoto Protocol, has been recently established the International Emission's Trading (IET), which is a flexible mechanism that gives companies the possibility to buy or sell emission licences to align the emissions with the assigned portion. Those emission licences are called Assigned Amount Units (AAUs), and its price is set from the international market. About it, Europe introduced the "Stock Exchange of CO_2" for the member Nations, that exhibits a national plant of licences allocation among industries, to commercialize their licences of industrial emission. The cost of these licences is strongly unstable, and currently it oscillates around 1 €/t. The national plan of licences allocation [1]

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highlights the hard burdens of thermoelectric business, with an annual average allocation about 131 Mt CO_2 for the period 2005-2007. If Italy wants to respect expected limits is necessary to identify different ways from buying of emission's licences. Moreover, during the preparation of this paper, the new national plan of licences allocation [2] for the period 2008-2012 has been submitted to the European Commission.

The introduction of the International Emission Trading and all the subsequent international and local rules, make more and more interesting the possibility to apply the carbon capture and sequestration (CCS) technologies, in particular in the field of power generation.

This paper reports a preliminary economic analysis on the introduction of CCS technologies at the power generation plants located and likely to be located into and nearby the Sulcis area, in South-West Sardinia. This area is particularly interesting for such analysis due to the presence of the only Italian coal mine. In particular, the Sulcis coal is a sub-bituminous coal characterized by a very high sulphur content (about 6%).

A preliminary technical analysis recently ran on the deep coal seams [3] showed that this coalfield is suitable for the application of the ECBM (Enhanced Coal-Bed Methane) technology for CO_2 geological storage with methane recovery.

Currently, the power generation plant located in the Sulcis area don't obey the CO_2 emission limit established within the licences and is necessary to buy other licences or pay a penalty for the CO_2 emitted beyond the limit. This study wants to offer the possibility of a solid alternative to buy licences of emission highlighting the economic advantage related to the integration of the power generation plant with a CO_2 separation unit and the possibility to inject CO_2 in the deep coal seams with the ECBM technology.

The Sulcis District

As already mentioned, the Sulcis coalfield (which has been discovered in 1851 and its exploitations started in 1889) is the only sub-bituminous coal basin in Italy, which extends for about 400 km^2 (see figure 1).

As for the antropic CO_2 sources, this area is mainly characterized by the Portovesme industrial district located in the Sardinian South-West coast. This district includes some large industries for the production of alumina and aluminium semifinished products (characterized by a low CO_2 emissions, which doesn't justify the introduction of CCS technologies) and two coal-based power generation plants, which have been considered in this study. Beside these two plants, this study consider the Sarlux IGCC plant, located near the Sulcis coal basin, and a new power generation plant which probably will be set up around 2012.

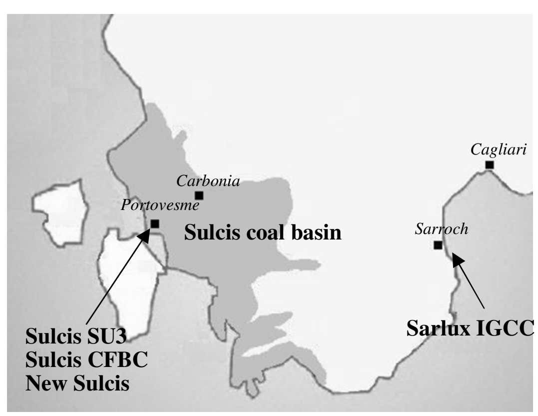


***Figure 1**. The Sulcis District.*

In brief, the four power generation plants considered in this study (see figure 1) are:

- Sulcis SU3, which is a 240 MWe group, property of ENEL and located in Portovesme industrial area, planned to use coal or fuel oil; it is working since 1986 and it is based on a conventional steam cycle; this plant is endowed with an electrostatic precipitator, a flue gas desulphurization system (by lime-based wet absorption) and a SCR denitrification process.

- Sulcis CFBC (Circulating Fluidised Bed Combustion), which is a 360 MWe circulating fluidized-bed combustion plant, property of ENEL, located in the Portovesme district; this plant entered in operation phase at the begin of 2006.
- Sarlux IGCC (Integrated Gasification Combined Cycle), which operates since 2000 and is the largest IGCC plant in the world (555 MWe); it is located in the Sarroch industrial area (in the South Sardinian coast) and it is fuelled by tar produced in the Saras S.p.A. refinery; the plant is composed by three different section: an entrained-flow gasification section (based on the Texaco process), a syngas treatment section (with the production of about 40000 Nm^3/h of hydrogen, used in the refinery) and an advanced power generation section [4-5].
- New Sulcis, a 650 MWe ultrasupercritical plant which is expected to come into operation in 2012 and which will be fuelled by a mixture of Sulcis and imported coal.

As already mentioned, the considered power generation plants (including the New Sulcis, which preliminary technical and economical evaluations has been recently developed) currently doesn't include any CCS system.

Table 1 shows the main parameters which characterize the considered power plants.

	Sulcis SU3	Sulcis CFBC	Sarlux IGCC	New Sulcis
Net Power output [MW]	240	360	555	650
Net efficiency [%] [(a)]	38%	38%	38%	43%
Availability [h/yr.]	6 500	7 700	8 000	8 000
Energy production [GWh/yr.]	1 560	2 772	4 440	5 200
Note: [(a)] LHV-based.				

***Table 1**. Main characteristic parameters of considered power plants.*

Assumption and analysis

In accordance with the International Emission Trading mechanism, the considered plants are subjected at the CO_2 emission limit. These limits (shown in table 2 together with the annual CO_2 production) have been calculated according with the criteria suggested by the new Italian plan of licences allocation [2] (which, during the writing of this paper, is not still subscribed by the European Commission).

In particular, the annual CO_2 production and the CO_2 emission limits shown in table 2 has been evaluated considering the Sardinian and the Italian energy system perfectly interconnected and it refer the situation in the year 2009, except for the New Sulcis plant, which evaluation is referred at year 2012.

The analysis here presented is based on the evaluation of the costs of CO_2 capture, compression, transport and sequestration using the ECBM (Enhanced Coal-Bed Methane) technology and all the subsequent operative costs (such as the costs derived for the reduction of power production due to the introduction of the CO_2 capture plant and the profit deriving from the methane production); these costs have been compared with the cost of the CO_2 emission licenses that the plants managers must be currently pay.

	CO_2 production [Mt/year]	CO_2 emission limit [Mt/year]
Sulcis SU3	1.740	1.243
Sulcis CFBC	2.346	1.786
Sarlux IGCC	3.509	1.691
New Sulcis	4.162	2.700

***Table 2**. Estimated CO_2 production and emission limits.*

CO_2 capture plants

As CO_2 capture system, an amine-based absorption process has been considered for all the four power plants (including the Sarlux IGCC, in which CO_2 must be separated after combustion in order to maintain the current configuration of the power generation section), due to its high reliability and, in particular, for the possibility to introduce such systems in existing plant without strong structural adjustments.

	Sulcis SU3	Sulcis CFBC	Sarlux IGCC	New Sulcis
Solvent	MEA	MEA	MEA	MEA
Power reduction [a]	20%	20%	20%	12%
CO_2 separ. efficiency	85%	85%	85%	90%
Capital cost [€/kW]	720	720	380	540
Global capital cost [M€]	172.8	259.2	210.9	351.0
Note: [a] with reference to the net power output.				

***Table 3**. Main assumptions on CO_2 capture process*

This kind of systems involves a reduction of the plant power generation, due to the high energy consumption of the process (in particular for solvent regeneration).

Table 3 shows the main assumption on the CO_2 capture process. In particular, the table reports the reduction of power generation [6] and the capital costs of the capture plants [7].

Is important to notice that a relatively low CO_2 separation efficiencies (85%) have been considered for the existing plants (a lightly rise of the capture efficiency involve a strong increasing of capital costs), while an efficiency value of 90% (according with the current state-of-the-art of the technology) has been considered for the New Sulcis plant; in any case, as a consequence of introduction of CCS systems, the CO_2 emission is lower than the amount allowed from licences. Moreover, the capital cost of the New Sulcis plant (540 €/kW) is lower than the same parameters referred to the existing coal-fired plant (720 €/kW for the Sulcis SU3 and the Sulcis CFBC, which require a few variations in the plant layout). As for the Sarlux IGCC, the same parameter is lower than the other considered plants.

The installation of the CO_2 absorption process affects significantly the costs of carbon capture and sequestration. For this reason, this capital costs have been considered with its straight-line amortization schedule [8], assuming the economic and financial parameters shown in table 4.

For each year of the project life, the annual rate of the capital and operating costs (which is the addition of the capital share and the annual interest) has been evaluated, together with the costs for loss of power production (assumed equal to 3.9 c€/kWh [7], with an annual increasing of 1% [9]) and the profits for the reduction of CO_2 emissions (economic savings resulting from failure penalty and profits resulting from sale of the surplus licences), considering a base-price for the CO_2 emission licenses of about 25 €/t (current price of CO_2 emission licences is about 1 €/t, due to the overallocation adopted in the periodo from 2005 to 2007 by several countries in their national plans, but in 2008 a significant rise of the CO_2 price can be expected).

Project life [yr.] [a]	20
Discount rate	7%
Inflation rate	2%
Plant construction period [months]	12
Start-up, spare parts, royalties, working capital [b]	5%
Engineering [c]	10%
Contingencies [c]	15%
Annual operative and maintenance costs [b]	4%
Notes: [a] as for the Sulcis SU3 plant, in operation since 1986, a project life of 8 years has been considered in this analysis; [b] % of plant cost; [c] % of component cost.	

***Table 4**. Economic and financial assumption*

CO_2 compression and transport

The concentrated CO_2 separated by the capture plant must be compressed at about 12-14 MPa and transported, through a pipeline, from the factory to the injection well.

The compression technology, based on a multistage intercooled compressor, is quite mature and does not need further development for applications with CO_2. Pipelining CO_2 is a well-estabilished technology, which uses the normal gas construction methods (potential problems are pipeline corrosion and gas-liquid two-phase flow) [10].

The compression and transport costs (including the capital costs of the infrastructures and the operative costs) have been assumed constant for each year. In particular, a compression cost of 0.75 c€/kg [11] have been considered (with reference to a CO_2 concentration between 83 and 97%). On the other hand, a transport costs of 1.4 c€/(t km) have been assumed [7], with reference to onshore pipelines.

The annual costs of CO_2 compression and transport are shown in table 5, together with the estimated length of the pipeline.

	Sulcis SU3	Sulcis CFBC	Sarlux IGCC	New Sulcis
CO_2 amount [Mt/yr.]	1.479	1.994	2.983	3.746
Pipeline length [km]	40	40	100	5
Annual costs				
Compression [M€/yr.]	11.09	14.96	22.37	28.09
Transport [M€/yr.]	0.83	1.12	4.18	0.26

***Table 5**. Annual costs of CO_2 compression and transport*

CO_2 geological storage

Due to the closeness of the considered power plants to the Sulcis coal basin, the most suitable technology for CO_2 sequestration is the Enhanced Coal-Bed Methane (ECBM). In particular, CO_2 injected into coal seams displaces methane, thereby enhancing coal-bed methane recovery. This process has the potential to increase the amount of produced methane to nearly 90% of the gas in compared with a conventional recovery of only 50% produced by means of reservoir-pressure depletion [12].

As already mentioned, a preliminary technical analysis recently conducted on the Sulcis coal basin [3] confirm the possibility to store a large CO_2 amount (about 200 Mt) in the deep coal seams.

Injection of compressed CO_2 into deep coal seams can be carried out with conventional drilling and well technologies; pumping of liquid CO_2 is relatively inexpensive [10].

A CO_2 storage cost of 0.3 c€/kg (which doesn't include the profit for methane production) has been considered in this analysis [7-13]. Moreover, for any ton of stored CO_2, it is possible to extract about 285 m^3 of methane [3-14]. Finally, the value of extracted methane has been assumed equal to 6.4 c€/m3, with a mean annual increase of about 3.2% [15].

On the basis on the aforementioned assumption, it is possible to evaluate, for each year of the project life, the costs of CO_2 geological storage and the profit for the methane selling, as shown in table 6.

	Sulcis SU3	Sulcis CFBC	Sarlux IGCC	New Sulcis
Amount of stored CO_2 [Mt/yr.]	1.479	1.994	2.983	3.746
Amount of produced methane [Mm^3/yr.]	421.5	568.3	850.0	1067.66
Annual costs and pofits				
CO_2 storage [M€/yr.]	4.44	5.98	8.95	11.24
CH_4 selling [M€/yr.] [(a)]	26.98	36.37	54.40	68.33
Note: [(a)] the values refer to the first year of plant operating life (2008 for existing plant and 2012 for New Sulcis).				

***Table 6**. Annual costs of CO_2 storage and methane selling*

Results and discussion

The global economic and financial balance of each investment is given by the sum of the net present values (referred to the first year of the project life) of the subsequent terms:

	Sulcis SU3	Sulcis CFBC	Sarlux IGCC	New Sulcis
Project life [yr.]	8	20	20	20
Global profit [M€]	71.32	211.06	608.06	929.60
Pay-back time [yr.]	7	10	6	7
Cost of avoided CO_2 [€/t]	38.79	34.27	30.82	26.34

***Table 7**. Global financial balance*

a) annual rate of capital and operative costs;
b) annual costs for loss of power production;
c) annual savings for loss of CO_2 emission;
d) annual profit for selling of CO_2 emission licences;
e) annual CO_2 compression costs;
f) annual CO_2 transport costs;
g) annual CO_2 sequestration costs;
h) annual profit for extracted methane selling.

The present value of the global profit which can be obtain by introduction of a carbon capture and sequestration system in the four considered power plants is shown in table 7, together with the pay-back time of each investment and with cost of avoided CO_2 emissions (which doesn't include the profit for methane selling).

The present value of the global profit results positive for all the power plants (in particular for the Sarlux IGCC and the New Sulcis, due to the lower capital costs for the introduction of the CO_2 capture plant). Nevertheless, the profit allowed from the Sulcis SU3 plant is very low and the investment cannot be recommended, the pay-back time being very close to the project life.

Another interesting results of the analysis is the evaluation of the cost of avoided CO_2, which is the cost for carbon capture, transport and storage (excluding the profits for selling emission licences and methane). The cost of avoided CO_2 from the Sulcis SU3 plant appears not competitive with the cost of emission licences (25 €/t), even if the profit of selling methane has been excluded from the evaluation; this confirm that the investment in this plant cannot be recommended; on the other hand, the cost of CO_2 separated from the other plant is competitive with the emission licences [7-10-16].

As already mentioned, the cost of the licences is strongly unstable. In the last year it has been characterized by a strong decreasing from about 30 €/t (May 2006) to about 1 €/t (March 2007), as shown in figure 2. With the introduction of the second phase of licences allocation (for the period 2008-2012) a new rise of the CO_2 price can be expected, but is very difficult to have a trustworthy evaluation of the price trend during the plant operation life. For this reason, a sensitivity analysis has been carried out in order to evaluate the effect of this parameter on the global financial balance (figure 3) and on the pay-back time (figure 4). To this aim, a very large range of variation (between 0 and 50 €/t) has been considered for the cost of CO_2 emission licenses.

In particular, with reference on figure 3, the analysis shows, for each considered power plant, a near linear increasing of the global financial balance subsequent to the rise of the cost of emission licenses. It is quite interesting to notice that for the Sarlux IGCC

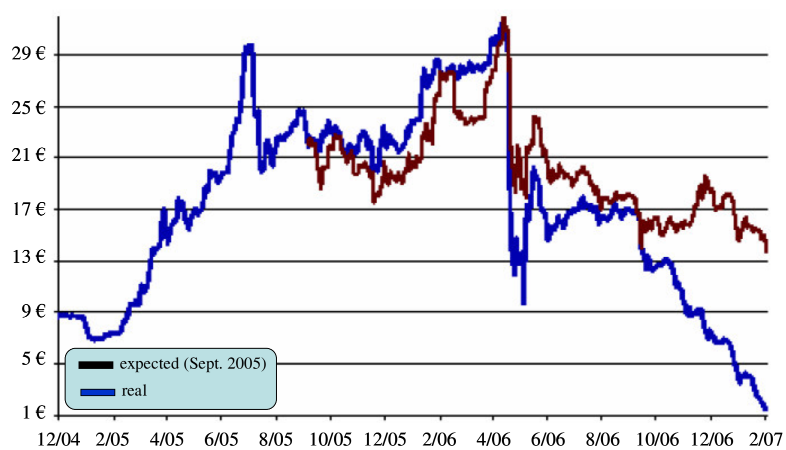


***Figure 2**. Trend of cost of emission licences [17].*

and New Sulcis the financial balance is positive even with the lower value of licenses cost. On the other hand, Sulcis CFBC and Sulcis SU3 power plants are characterized by a positive financial balance only when the cost of licences is higher than 15 and 20 €/t, respectively.

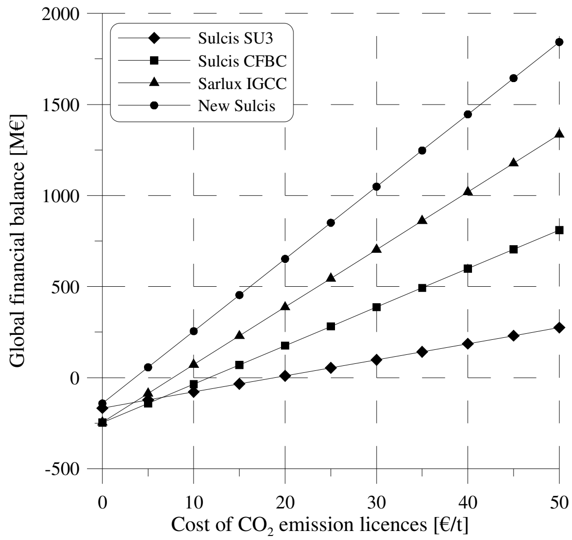


***Figure 3**. Variation of global financial balance with cost of CO_2 emission licenses.*

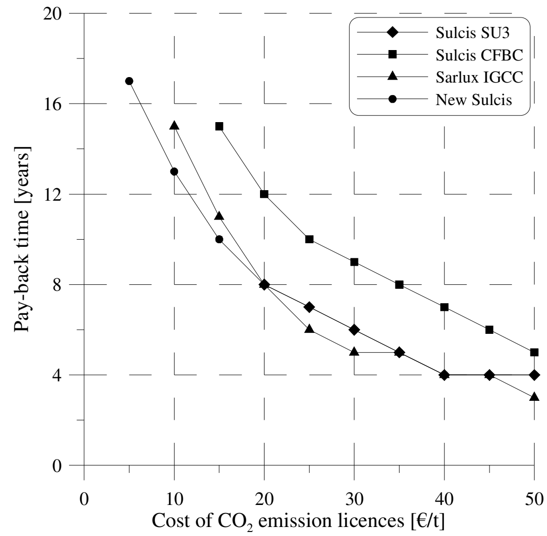


***Figure 4**. Variation of pay-back time with cost of CO_2 emission licenses.*

With reference on figure 4, the analysis shows a strong influence of licenses cost on the plant pay-back time. In particular, an increasing of the licenses cost involves a reduction of the pay-back time due to the higher profits for the selling of the licenses themselves.

Moreover, the preliminary technical study [3] recently conducted on the deep coal seams (which presents a methane production of about 285 m^3 for any ton of stored CO_2) is not based on local sounding but only on the application of two different empirical methods; therefore, a sensitivity analysis have been conducted in order to evaluate the influence of the specific amount of produced methane (cubic meters of extracted methane per ton of stored CO_2) on the global financial balance (figure 5) and on the pay-back time (figure 6) for the considered power plants.

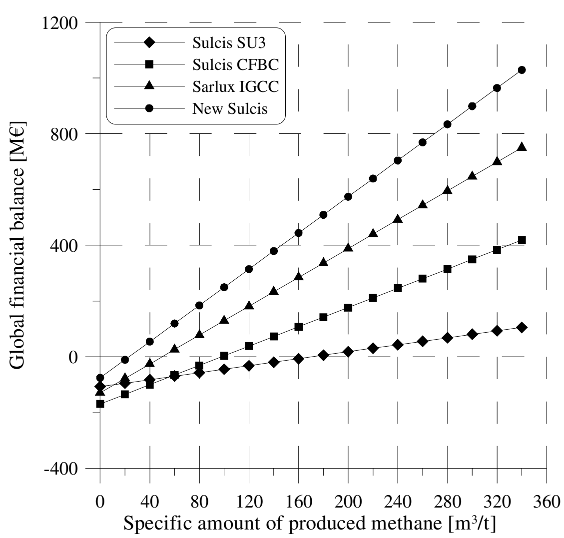


***Figure 5**. Variation of global financial balance with methane production.*

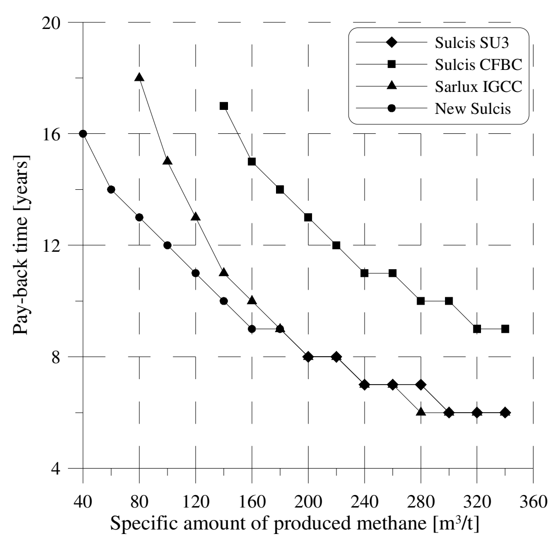
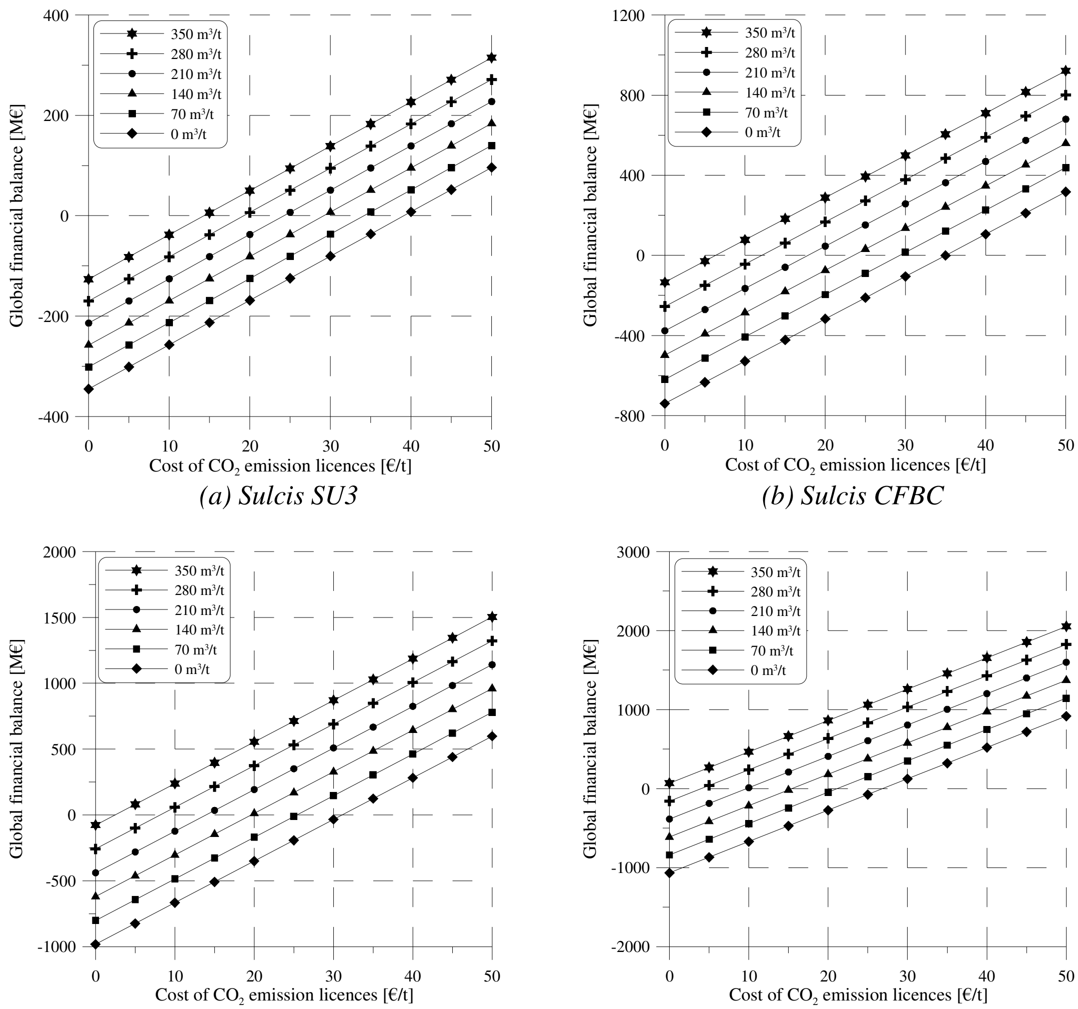


***Figure 6**. Variation of pay-back time with methane production.*

In particular, figure 5 shows that the introduction of a CCS system with ECBM technology on Sarlux IGCC and New Sulcis power plants are profitable even with a very low amount of extracted methane (74.31 and 23.23 m^3/t respectively). On the other hand, the investment on the Sulcis CFBC plant can be profitable only if the specific amount of extracted methane is higher than 122.3 m^3/t. Finally, the investment on the Sulcis SU3 plant needs an amount of extracted methane of 200 m^3/t.

As for the pay-back time, figure 6 shows the strong influence of the specific amount of extracted methane on this parameter. As expected, IGCC Sarlux and New Sulcis power plants are characterized by a pay-back time which ranges between 6 and 18 years, to be compared with the project life of 20 years; therefore, the investment for these plants can be convenient even with a low methane production. Whereas, Sulcis CFBC plant is characterized by a higher pay-back time and the investment on this plant can be profitable only with a medium amount of methane extraction. Finally, Sulcis SU3 plant presents a pay-back time between 6 and 8 years, to be compared with the project life of 8 years; therefore the investment appears unprofitable even with a high methane production.

In order to analyze the effect of both considered parameters (the cost of CO_2 emission licences and the specific amount of produced methane) on the global financial balance of each plant, a combined sensitivity analysis have been carried out (figure 7).



(a) Sulcis SU3 (b) Sulcis CFBC

(c) Sarluc IGCC (d) New Sulcis

***Figure 7**. Combined sensitivity analysis.*

In particular, for each plant, the line representing the variation of the global financial balance with the cost of CO_2 emission licences translates vertically with the rise of the specific amount of produced methane.

Conclusions

As a consequence of the implementation of Kyoto Protocol and the introduction of International Emission's Trading (IET), the Carbon Capture and Sequestration (CCS) technologies are being more and more interesting, in particular for their application in power generation plants.

These technologies can be particularly profitable in the Sulcis area (South-West Sardinia), due to the presence of the only Italian sub-bituminous coal basin (which can be used to store a very large amount of CO_2 in its deep seams).

This paper presents the main results of a preliminary technical and economic analysis on the application of CCT technologies on the power generation plants already located and likely to be located inside and nearby the Sulcis area. In particular, four plants have been considered: a conventional 240 MW coal-based steam cycle; a 360 MW coal-based CFBC plant; a 555 MW integrated gasification combined cycle, fuelled with tar produced in a refinery; an innovative 650 MW ultrasupercritical plant, fuelled with coal, which is expect to come into operation in 2012.

The analysis considers an amine-based CO_2 capture system (which operates on plant's flue gas), a conventional carbon dioxide compression system, an onshore pipeline for the transport and the ECBM (Enhanced Coal-Bed Methane) technology for the carbon sequestration.

The analysis shows that the application of CCS technologies can be strongly profitable for the Sarlux IGCC and for the New Sulcis plant, due to the high global profits (higher than 600 M€) and the relatively low pay-back time (6 and 7 years, respectively). A lower profit (about 200 M€) can be obtained for the Sulcis CFBC plant, which can allow a pay-back time of 10 years. Finally, the investment on the Sulcis SU3 plant appear unconvenient due to a low global profit (about 70 M€) and a high pay-back time (7 years, to be compare with the 8 years of project life).

Moreover, due to the strong instability of the cost of emission licenses and to the uncertainty of the specific amount of produced methane, a sensitivity analysis have been carried out, in order to evaluate the influence of these parameters on the global financial balance and the pay-back time. In particular, the investment on the Sarlux IGCC and New Sulcis plants can be profitable even with low costs of emission licences (higher than about 10 €/t) or low methane production (60-80 m^3 of methane per ton of stored CO_2). The investment on Sulcis CFBC results less convenient than the above-mentioned plants for the need of higher values of the cost of emission licences (about 15 €/t) or higher methane production (about 100-120 m^3/t). Finally, the investment on Sulcis SU3 plant can be profitable only with high values of CO_2 emission licences (more than 20 €/t) and methane production (200 m^3/t).

The analysis shown in this paper is only a preliminary stage of a more detailed theoretical and experimental study, which Sotacarbo is starting to carry out, on the application of the ECBM technology on the Sulcis coal basin. The main results of this preliminary economic evaluation is to suggest the development of a detailed business plan on the application of CCT technologies to the power generation plant located in the Sulcis area.

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