A hypothesis of a 650 MW zero-emissions plant integrated with a sub-bituminous coal mine in South-West Sardinia

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Abstract

The implementation of Kyoto protocol, the subsequent introduction of the International Emissions Trading and the increasing interest on the environmental protection are making more and more interesting the development of the "zero emissions" power generation technologies, in particular from coal.

This paper reports a plant configuration which appears particularly suitable for an application in close integration with the sub-bituminous coal mine located in the Sulcis area, in South-West Sardinia.

The considered plant is based on a 1500 MW_{th} ultrasupercritical (USC) boiler, which will be fed by a mixture of a local high-sulphur coal (which is characterized by a sulphur content of about 6-7%) and an imported low-sulphur coal.

Due to the particular properties of the combustion process, the produced ashes can be used in the coal mine, as a filling material, or recovered for the building industry. Moreover, the plant include a high performance SNOX system, for the combined nitrogen oxides and sulphur oxides removal (with the production of high purity sulphuric acid as by-product).

Finally, this study considers the possibility to introduce a carbon capture and sequestration system, in order to have a CO_2-free plant. In fact, carbon dioxide can be captured from flue gas through an absorption system based on chemical solvents, and the CO_2-rich stream can be injected, without significant costs for transport, in the deep and unminable coal seams, with a methane production through ECBM (Enhanced Coal-Bed Methane) technology.

This paper presents the main results of the preliminary technical and economical analysis carried out in order to evaluate the feasibility of the project and to evaluate the opportunity to equip the plant with a CCS system.

Introduction

Power generation in Italy is based for about 75% on fossil fuels, with a global CO_2 emission of about 460 Mt per year, as shown in figure 1. Moreover, only 8.3% (corresponding to about 16 million tons of oil equivalent, toe) of fossil fuel used for power generation comes from the national production, while the remaining 91.7% is imported [1]. For this reason, the Sulcis coal basin, located in South-West Sardinia, can play an important role for the national energy security.

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The Sulcis coal is a sub-bituminous coal characterized by a very high sulphur content (about 6%) and a lower heating value of about 20-21 MJ/kg. It is currently used in very small amount in two power generation plants located near the coal basin.

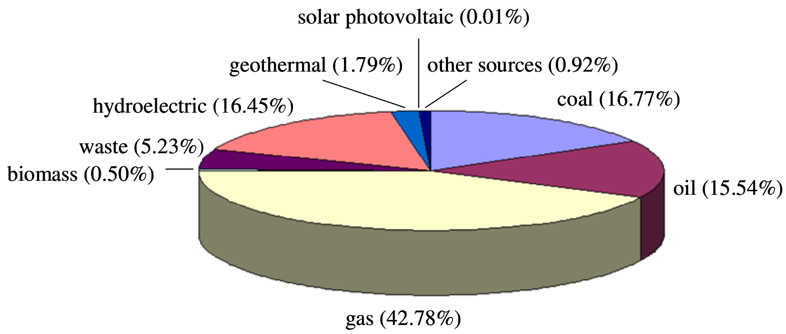

***Figure 1** – Energy balance in Italy in 2004 [1].*

In order to increase the production of the coal mine (and to give an important contribute for the solution of the occupation problems in the Sulcis area), the Italian Government has been developed a series of laws regarding the reactivation of the coal mine, the environmental control and the energy supply for the industries operating in the Sulcis area. As a consequence of these laws, a project for an integrated gasification combined cycle (Sulcis IGCC project) has been developed, but, in 2002, the realization of the plant has been considered not economically profitable due to the restrictive requested financial guarantees.

In this scenario, Sotacarbo developed a hypothesis of a power generation plant which operates in integration with the Sulcis coal mine. The hypothesis, in its basis configuration, regards a plant characterized by near zero pollutants emissions and it does not include the CO_2 capture and sequestration. However, as a consequence of the implementation of Kyoto Protocol and the subsequent introduction of the International Emissions Trading, the possibility to introduce a carbon capture and sequestration (CCS) system has been considered, in order to obtain a near zero emissions plant.

The International Emissions Trading

With the Kyoto Protocol, the main Industrial Countries committed themselves to obtain, before 2012, a global reduction of greenhouse gases emissions of 5.2%, compared to those of 1990. Every Country has different goals and Italy must reduce the greenhouse gases emissions of 6.5%.

For the implementation of Kyoto Protocol, has been recently established the International Emissions 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 plan of licences allocation among industries, to commercialize their licences of industrial emissions. The cost of these licences is strongly unstable, and currently it oscillates around 1 €/t. The national plan of licences allocation [2] highlights the hard burdens of thermoelectric business, with an annual average allocation of about 131 Mt CO_2 for the period 2005-2007. Moreover, during the preparation of this paper, the new national plan of licences allocation [3] for the period 2008-2012 has been submitted to the European Commission.

The introduction of the International Emissions Trading plays an important role on the feasibility study of a power generation plant; in particular, it implies a strong influence in the economical and financial evaluations. As a matter of facts, a power generation plant not equipped with a carbon capture and sequestration (CCS) system need to buy the licences exceeding the assigned emission limit; on the other hand, the introduction of a CCS system involves a higher capital costs, but is possible to sell the emission licences (the real CO_2 emission is lower than the assigned emission limit).

In the considered case, due to the closeness of the plant to the Sulcis coal basin, the ECBM (Enhanced Coal Bed Methane) technology can be used for carbon sequestration. In this case, the profit for the extracted methane selling must be considered.

In this study, the criteria indicated from the new national plan of licences allocation (which is currently under verifying from the European Commission) have been considered to calculate the emission limit for the ultrasupercritical power plant. In particular, according with the plan, the considered plant (which is expected to come into operation in 2012) can be classified as a "new thermoelectric plant". Therefore, the national plan indicates the following equation for the calculation of the annual emission limit [3]:

$$Q_i = P \cdot \frac{h \cdot \alpha}{1000} \cdot T_i$$

where Q_i is the limit for the year i (in tons per year), P is the power output (650 MW), h is the conventional annual plant availability (6900 hours per year for steam cycles), α is an emission coefficient correlated to the particular kind of plant (757 kg of CO_2 per MWh for coal-feed steam cycles) and T_i is a coefficient which depends to the behaviour of the energy production for each year. As for the coefficient T_i, the national plan indicates a value of 0.8 for the year 2012 and a yearly decreasing of 0.01 has been assumed for the subsequent years.

As already mentioned, the cost of CO_2 is set from the international market; therefore it is strongly unstable and currently it oscillates around 1 €/t. 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, as a consequence of a strong licences overallocation operated by three European Countries. 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 life. In any case, in this analysis a medium price of 25 €/t has been considered during the plant operating life.

The analysis here presented, which is strongly influenced by the cost of emission licences and by the behaviour of the assigned emission limits, is characterized by a significant uncertainty; for this reason, a sensitivity analysis has been carried out in order to evaluate the effect of these parameters on the economic and financial performances of the plant.

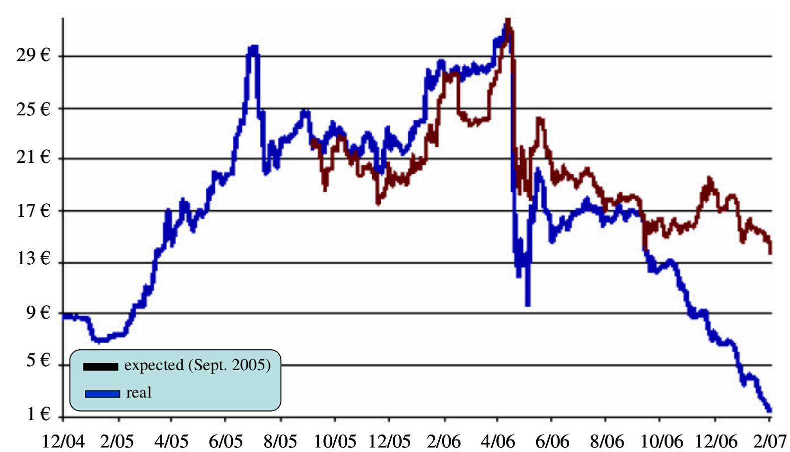

***Figure 2** – Trend of cost of emission licences [4].*

The power generation plant integrated with the coal mine

The analysis of the state-of-the-art of the technologies for power generation in the Sulcis area through large-scale power plants (between 300 and 700 MW_e) indicates three main technologies: ACFBC (atmospheric circulating fluidized bed combustion), IGCC (integrated gasification combined cycle) and USPCC (ultra-supercritical pulverized coal combustion). In particular, ACFBC plants allow to obtain a very low pollutant emission but involve a high production of waste materials (like calcium sulphate and calcium carbonate, deriving from calcium-based sorbents used for "in situ" desulphurization, and ashes). On the other hand, IGCC plants allow an advantage in terms of pollutant emissions and solid residues [5], but this kind of technology at the moment could be disadvantageous from the economical-financial point of view.

Therefore, the Sotacarbo hypothesis considers an ultrasupercritical plant, based on an advanced high temperature boiler (580-600 °C), equipped with a SNOX system in order to respect the emissions limits in terms of sulphur and nitrogen oxides.

The plant location has been assumed very close to the coal mine, in order to strongly reduce the transportation costs for the local coal and for the ash, which can be permanently stored in the exhausted seams of the coal mine.

The amount of Sulcis coal in the feeding mixture could be much higher than possible; on the other hand, an excessive amount of Sulcis high sulphur coal involves a higher SOx emissions in the flue gas. Therefore, for the considered plant, a mixture composed for the 50% (in terms of energy contribution) of Sulcis high sulphur coal and for the remaining 50% of imported high quality coal (with a sulphur content lower than 0.5-0.6%) has been assumed. It corresponds to an amount of Sulcis coal of about 0.9-1.0 Mt/year.

The definition of the plant size is a consequence of the emission limits and the amount of Sulcis coal used in the plant. In particular, considering a plant availability of about 7500-8000 hours per year, an optimum size of 1500 MW_{th} can be assumed; in the basis configuration, considering a net plant efficiency of 43%, it corresponds to a net power output of 650 MW. In particular, in order to allow a flexibility and a reliability in power generation, the considered plant is modular and composed by two identical groups.

The main plant parameters and performances are reported in table 1 for the basis configuration and for the plant equipped with CCS system. In particular, the introduction of the CO_2 capture section (based on an absorption process which uses chemical solvents like monoethanolamine) involves a reduction of the net power output of about 12% (due to the high energy absorption, in particular for solvent regeneration process).

	Basis configuration	Plant with CCS system
Net power output [MW]	650	572
Gross thermal input [MW]	1500	1500
Net efficiency (LHV-based)	43%	38%
Power absorption in CO_2 capture [(a)]	-	12%
Sulcis coal in the fuel blend [(b)]	50%	50%
Availability [h/yr.]	8000	8000
SOx removal efficiency (SNOX)	98-99%	98-99%
NOx removal efficiency (SNOX)	90-95%	90-95%
CO_2 emissions [Mt/yr.]	4.16	0.42

Notes:
[(a)] With respect to the net power output of the basis configuration.
[(b)] In terms of energy contribution.

Table 1 *– Main plant performances.*

As for the pollutant emissions, the need to respect the limits (in terms of tons per year) suggests to use a SNOX system for the combined catalytic removal of sulphur and nitrogen oxides.

	Global emissions [t/year] [(a)]	Concentrations [mg/Nm^3] [(b)]
SOx	2280	150
NOx	2015	125
Particulate	103	5
Carbon monoxide	1300	120

Notes:
[(a)] Referred to a plant availability of 8000 hours per year.
[(b)] Referred to a O_2 concentration in flue gas equal to 6%.

Table 2 *– Main pollutant emissions.*

In the SNOX process, the sulphur contained in the flue gas is recovered as commercial grade concentrated sulphuric acid while NOx is reduced to N_2. The process does not consume water or other materials, except for ammonia used for the catalytic NOx reduction; moreover, it does not generate any secondary source of pollution, such as waste water, slurries or solids [6]. Table 2 shows the global pollutant emissions and the SOx, NOx, particulate and CO concentrations in flue gas.

Preliminary financial and economical analysis

The preliminary financial and economical analysis of both configurations of the power plant (with or without carbon capture and sequestration system) allows to calculate, for every year of plant life, the effective and actualized cash flow, the latter referred to the first year of the project financing phase (2008).

Capital costs

The evaluation of the plant capital costs considers the main phases of the plant construction and the adjustment of the infrastructure. In particular, a plant construction period of four years (from 2008 to 2011) have been considered. The capital costs estimation for the basis plant configuration is shown in table 3.

	Cost
Power generation plant [(a)]	944.5 M€
Material handling	76.4 M€
Other costs [(b)]	304.4 M€
TOTAL [M€]	*1325.3 M€*
Notes: [(a)] Without CCS system. [(b)] It includes the costs for the coal mine modernization and other investment and unexpected costs	

***Table 3** – Capital costs estimation (basis plant configuration).*

In particular, a detailed cost distribution for the construction of the power generation plant is shown in table 4. The total investment cost is composed by the sum of equipment costs, material costs, direct and indirect labor, engineering costs and contingencies. As for the equipments, the most significant contribute in the total plant cost comes from the ultrasupercritical boiler, the steam turbine system and the flue gas cleanup (which globally represents about 51% of the total plant cost).

The capital costs affect significantly the behaviour of the investment cash flow. For this reason, this costs have been considered with its financial amortization schedule [7].

	Equipm. costs	Material costs	Labor (direct)	Labor (indir.)	Engin. &fee	Conting.	*TOTAL*
Coal/sorbent handling	13.36	3.94	10.18	0.71	2.25	6.09	*36.54*
Coal/sorbent prepar. and feed	16.72	0.00	5.23	0.36	1.78	4.82	*28.92*
Feedwater and misc. BoP	34.17	0.00	14.93	1.05	4.01	12.58	*66.75*
PC boiler and accessories	124.41	0.00	50.29	3.52	14.26	19.25	*211.72*
Flue gas cleanup	66.00	0.00	37.01	2.30	8.43	10.68	*124.42*
Ductwork and stack	18.58	0.55	13.78	0.96	2.71	5.67	*42.25*
Steam turbine generator	94.48	0.72	24.70	1.73	9.73	16.14	*147.52*
Cooling water system	15.46	8.04	14.62	1.02	3.13	7.54	*49.82*
Ash/spent sorbent handling	11.55	0.15	21.12	1.48	2.74	5.62	*42.67*
Accessory electric plant	18.50	5.77	15.74	1.10	3.29	7.28	*51.69*
Instrumentation and control	12.39	0.00	10.27	0.72	1.87	3.93	*29.19*
Improvements to site	3.79	2.18	7.59	0.53	1.13	4.56	*19.78*
Buildings and structures	0.00	30.24	36.26	2.54	5.52	18.64	*93.20*
TOTAL	*429.43*	*51.60*	*261.74*	*18.03*	*60.86*	*122.81*	*944.47*

***Table 4** – Power generation plant cost distribution [8].*

Table 5 shows the main economic parameters assumed in this analysis. In particular, the annual rate of the capital cost (which is the addition of the increasing capital share and the decreasing annual interest) amounts to 268.34 M€ and it has been assumed constant for the eight years of the financial amortization schedule.

Plant construction period [years] [(a)]	4
Plant operating life [years] [(b)]	>20
During of financial amortization [years]	8
Discount rate	7%
Inflation rate	2%
Start-up, spare parts, royalties, working capital [(c)]	5%
Engineering [(d)]	10%
Contingencies [(d)]	15%
Annual operative and maintenance costs [(c)]	4%

Notes:
[(a)] Since 2008 to 2011.
[(b)] Since 2012 to 2031.
[(c)] % of plant cost.
[(d)] % of component cost.

***Table 5** – Economic and financial assumptions.*

As for the CO_2 capture plant, an extra capital cost of about 540 €/kW must be consider. Therefore, the introduction of the CCS system involves an increasing of the global capital cost of about 300 M€ (it affects for about 25% the total cost of the power generation plant).

Global operative costs

The global operative cost of the power generation plant is the sum of costs for extraction of the Sulcis coal, purchasing of imported coal, managements and maintenance of the plant, material handling and taxes. In particular, the cost for fuel supplying impacts for about 75% on the global operating cost, while the O&M (operative and maintenance) costs impact for about 15%.

The cost for extraction of Sulcis coal corresponds with all the costs for coal mine operation and maintenance. On the other hand, for the imported coal a price of about 40 €/t has been considered, with an annual increasing of 2% in order to consider the current trend of the price.

The operative and maintenance costs include all the costs for conduction and maintenance of the power generation plant and, in particular, the cost of labour, the day-by-day maintenance, the cost for spare parts and so on.

Cost/profit for CO_2 emission licences

The price for the purchasing or the selling of the CO_2 emission licences strongly influences the project cash flow. In particular, for the basis plant configuration, the International Emissions Trading (IET) involves a cost for the purchase of the licences; on the other hand, if the plant is equipped with a CCS system, the CO_2 emission is lower than the plant emission limit and the IET involves a profit from the selling of exceeding licences.

In both cases, this cost (or profit) has been evaluated considering constant the price of CO_2 emission licences (as already mentioned, a medium value of 25 €/t has been considered during the plant operating life) and the global carbon dioxide production (4.16 Mt/year). Therefore, an annual decreasing of the emission limit involves a rise of the global cost for the purchasing of the licences (from 36 M€ in 2012 to 52 M€ in 2031) for the basis plant configuration or a reduction of the global profit (from 49 M€ in 2012 to 35 M€ in 2031) for the plant equipped with CCS system.

Profits for energy and by-products production

The electrical energy produced by the power generation plant is mainly sold to the national electric grid and represents the main profit of the industrial application. Moreover, a part of the produced energy (assumed equal to 23% in this preliminary analysis) is used to contribute to the power request of the industrial area located near the coal mine.

The profit for the selling of produced energy to the national grid (and, in particular, to GSE S.p.A., the Italian company for the management of the electrical services), has been calculated with reference to the ordinance CIP 6/92 [9], which defines the price of electricity on the basis of the "avoided costs" and, in particular, as the sum of plant avoided costs, operative avoided costs and fuel avoided costs. Moreover, for the first eight years of the plant operating life (since 2012 to 2019), GSE pays an extra incentive for energy selling, according with the Italian law d.p.r. 28/01/94. The price of the electrical energy sold to the national grid is shown in table 6, with reference to the first year of the plant operating life (2012); for the subsequent years, an annual increasing of 2% has been considered.

	Price [(a)] [c€/kWh]
- plant avoided costs	*2.27*
- operative avoided costs	*0.79*
- fuel avoided costs	*2.39*
Global avoided cost	5.45
Incentive	6.92
Global price of energy	12.37
Note: [(a)] Referred to the first year of plant operation (2012).	

Table 6 *– Price of electrical energy sold to GSE.*

After the eighth year (since 2020), when the payment of incentive is suspended, a slight charge of the energy price (0.74 c€/kWh, with reference to year 2020) must be considered, according with the Italian law d.p.r. 28/01/94.

As for the electrical energy sold to the local market, the price has been calculated considering the marginal cost of energy production (assumed equal to the variable costs of the project, in terms of total variable costs per produced kWh) and a mark-up corresponding to the 20% of the fixed costs (with reference to the first year of the plant operating life). Globally, the price of electricity sold to the local market corresponds to 3.10 c€/kWh in 2012.

Every component of the global price of the electrical energy sold to GSE an to the local market has been calculated for every year of the plant operating life in order to consider the estimated inflation rate. The trend of the global profit from the selling of produced energy is shown in figure 3.

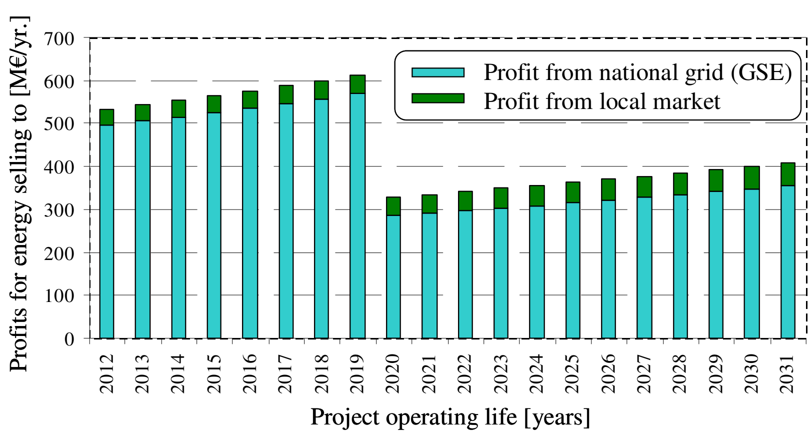

Figure 3 *– Trend of profit from energy selling.*

As for the by-products, the SNOX process produces about 240˙000 tons per year of high quality sulphuric acid, which can be commercialized. In this evaluation, the profit for the selling of this by-products has been considered equal to the cost for ash disposal in the coal mine.

Costs and profits for ECBM technology

As for the plant configuration with CCS system, a few costs or profits must be considered for the determination of the project cash flow. In particular, as already mentioned, for the carbon geological storage the ECBM (Enhanced Coal Bed Methane) technology has been selected, due to the closeness of the considered power plants to the Sulcis coal basin. 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 [10]. This technology needs some capital and operative costs for CO_2 compression, transport and storage and allows a significant profit due to the methane production.

The concentrated CO_2 separated by the capture plant must be compressed at 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) [11].

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 [12] 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 [13], with reference to onshore pipelines. The annual costs of CO_2 compression and transport are shown in table 7, together with the estimated length of the pipeline.

A preliminary technical analysis recently conducted on the Sulcis coal basin [14] confirms the possibility to store a large CO_2 amount (about 200 Mt) in the deep coal seams. Injection of compressed CO_2 can be carried out with conventional drilling and well technologies; pumping of liquid CO_2 is relatively inexpensive [11]. 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 [13-15]. Moreover, for any ton of stored CO_2, it is possible to extract about 285 m^3 of methane [14-16]. Finally, the value of extracted methane has been assumed equal to 6.4 c€/m^3, with a mean annual increase of about 3.2% [17]. On the basis on the aforementioned assumption, it is possible to evaluate, for each year of the project life, the cost of CO_2 geological storage and the profit for methane selling, as shown in table 7.

Process parameters	
Amount of stored CO_2 [Mt/yr.]	3.75
Pipeline length [km]	5
Amount of produced methane [Mm^3/yr.]	1068
Annual costs and profits	
CO_2 compression cost [M€/yr.]	28.10
CO2 transport cost [M€/yr.]	0.26
CO2 storage cost [M€/yr.]	11.24
Profit for methane selling [M€/yr.] [(a)]	79.88
Note: [(a)] the values refer to the first year of plant operating life (2012).	

Table 7 *– Annual costs and profits for ECBM technology.*

Results and discussion

The global cash flow of the project includes, for every year of the operating life, the capital and operative costs, the profit for energy selling and the cost (or profit, in the case of the CCS system) for purchase (or selling) of CO_2 emission licences. Moreover, as for the plant equipped with the CCS system, the costs for CO_2 compression, transport and injection and the profit for methane selling must be considered.

The financial amortization schedule has been distributed in eight years, corresponding to the period of GSE incentive. Therefore, between the eighth and ninth year of the plant operating life only a slight decreasing of the cash flow takes place for the basis plant configuration (figure 4); in facts, the decreasing of the profit for selling energy to GSE is higher than the annual rate of the capital cost. On the other hand, the plant equipped with the CCS system is characterized by a different trend. This case presents a higher annual rate of the capital cost (331 M€ vs. 268 M€) and a lower energy production (280 M€ vs. 320 M€, with reference to the GSE incentive contribute in the eighth year of operating life) with respect to the basis configuration; therefore, between the eighth and ninth year a strong rise of the annual cash flow takes place.

Figure 5 shows the present value (referred to the year 2008) of the annual cash flow for both plant configurations.

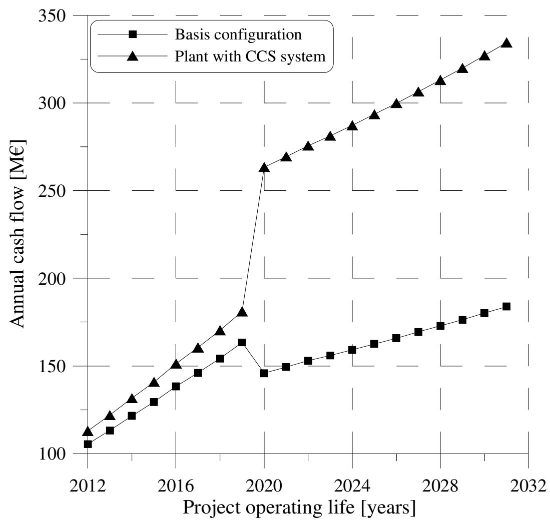

Figure 4 *– Effective annual cash flow.*

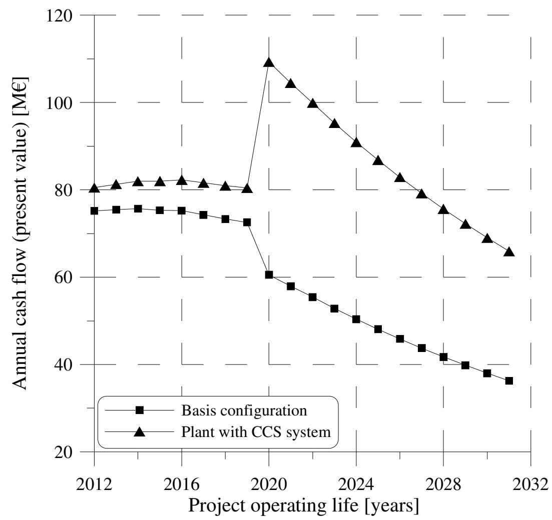

Figure 5 *– Annual cash flow present value.*

The two different plant configurations can be compared with reference to two financial parameters: the global cumulative profit at the end of the operating life and the payback time.

Assuming a medium price of CO_2 emission licences of 25 €/t, the values of these parameters for both plant configurations are shown in table 8. Moreover, in the same table, the cost for production of electrical energy and the cost for avoided CO_2 are reported. In particular, the first is the ratio between the total capital and operating costs and the total produced energy during all the plant life, while the latter represents the specific cost for CO_2 capture, compression, transport and sequestration.

	Basis configuration	Plant with CCS system
Global cumulative profit [M€]	1444	2765
Payback time [years]	12	11
Cost of electricity [c€/kWh]	2.59	1.87
Cost of avoided CO_2 [€/t] [(a)]	-	14.25
Note: [(a)] Referred to the net present value of each considered cost.		

Table 8 *– Main plant economic performances.*

The analysis of these preliminary results allows a first comparison between the two plant configurations. As a matter of facts, the extra capital cost requested for the CCS system allows, during all the plant operating life, an extra global profit of about 1300 M€ and a lower payback time (11 years, to be compared with 20 years of plant operating life). Moreover, the cost of electricity, in the configuration with CCS system, is significantly lower than those correlated with the basis plant configuration (1.87 c€/kWh vs. 2.59 c€/kWh).

As for the cost of avoided CO_2, the analysis shows the theoretical convenience to operate the CO_2 carbon and sequestration until the price of CO_2 emission licences remains higher than 14-15 €/t.

Sensitivity analysis

As already mentioned, the cost of the licences (assumed equal to 25 €/t) can be strongly unstable; moreover, the preliminary technical study [14] recently conducted on the deep coal seams (which presents a methane production μ 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 has been conducted in order to evaluate the influence of both these parameters on the global financial balance (i.e. the cumulative profit at the end of project life, shown in figure 6) and on the pay-back time (figure 7) for the two configurations of the power plant.

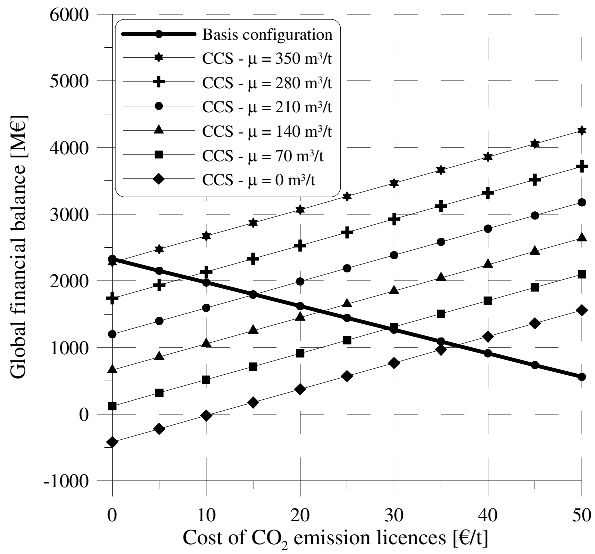

Figure 6 *– Sensitivity analysis on global financial balance.*

In particular, figure 6 shows that a rise of the cost of CO_2 emission licences involves, for the basis plant configuration, a decreasing of the global financial balance. An opposite trend can be observed with reference to the plant equipped with CCS system, due to the higher profits from the selling of extra licences. Moreover, an increasing of the specific amount of produced methane (μ) involves a rise of the global profit at the end of the project life. With reference to the expected values of the specific amount of extracted methane (250-300 m^3/t), the introduction of a CCS system can be profitable if the cost of CO_2 emission licences is higher than 10-15 €/t.

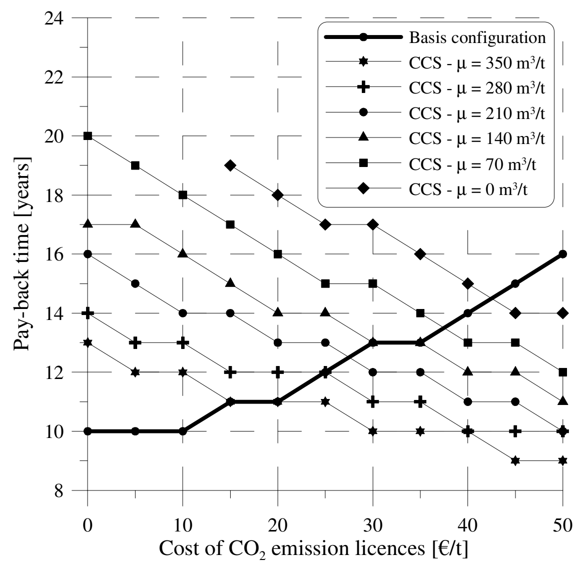

Figure 7 *– Sensitivity analysis on pay-back time.*

Figure 7 shows the pay-back time for the two plant configurations. In particular, low values of the cost of CO_2 emission licences involve a very high pay-back time for the plant with CCS system (around 13-15 years, with reference to the expected value of the specific amount of extracted methane) and suggest the realization of the basis plant configuration.

Conclusions

In order to assure a higher energy security (partially releasing energy production from imported primary sources) and to relaunch the Sulcis coal mine activities (giving an important contribute for the solution of the occupation problems in the Sulcis area), Sotacarbo has been developed a hypothesis of a power generation plant which operates in close integration with the coal mine. The basis proposal regards a plant configuration characterized by a near zero pollutants emissions and it does not include the CO_2 capture and sequestration. However, as a consequence of the implementation of Kyoto Protocol and the subsequent introduction of the International Emissions Trading, the possibility to introduce a carbon capture and sequestration (CCS) system has been considered, in order to obtain a near zero emissions plant.

As for the CCS system, an amine based absorption process has been considered for carbon dioxide capture; moreover, due to the closeness between the power plant and the coal mine, the ECBM (Enhanced Coal Bed Methane) technology has been selected for carbon geological sequestration.

The analysis considers, for every year of the plant life, the project annual cash flow, calculated as the addition of the main costs and profits correlated to the plant building and operation. In particular, the capital and operative costs, the costs or profits for CO_2 emission licences commercialization, the profits for energy and by-products selling have been considered for both plant configurations.

The preliminary evaluation considers a medium price of the CO_2 emission licences (during the plant operating life) of 25 €/t and, for the plant configuration equipped with CCS system, a specific amount of produced methane equal to 285 m^3 for every ton of stored CO_2. With reference to these assumption, both plant configurations allow a relatively higher global profit (about 1400 M€ for the basis configuration and about 2800 M€ for the plant equipped with CCS system) and a pay-back time of about 11-12 years, to be compared with a plant operating life of 20 years.

Due to the instability of the price of CO_2 emission licences and to the uncertainty of the specific amount of produced methane (determined through the application of two different empirical methods), a sensitivity analysis have been conducted in order to evaluate the influence of both these parameters on the main economical and financial performances of the project. In particular, for the expected values of the specific amount of extracted methane (250-300 m^3/t), the introduction of a CCS system can be profitable if the cost of CO_2 emission licences is higher than 10-15 €/t.

Is important to specify that the analysis here presented is only a preliminary stage of a more detailed theoretical and experimental study which Sotacarbo is carrying 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 CCS technologies to all the power generation plants located in the Sulcis area.

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