ABSTRACT

Thermal electricity generation has great importance on the security of electricity grids and also in energy costs control.

In Portugal, last 7 years, coal plants supplied an average of 22.3% of consumption.

But burning coal raises environmental problems, such as air emissions, which requires the introduction of specific technologies to minimize its effects.

This includes dust removal, desulphurisation and denitrification.

Products resulting of this equipments operation, fly ash, bottom ash and FGD gypsum, should be disposed in large landfills, if nothing was done.

The aim of this study is to show that, with the right management, coal combustion products can no longer be considered as industrial waste but, instead, they are raw materials, with commercial value.

Economic evaluation of its utilisation is also shown.

Keywords: Electricity generation, thermal power, coal, environment, coal combustion products, fly ash, bottom ash, gypsum

1 – INTRODUCTION

In electricity generation technologies associated with coal have an important role in consumption supply.

Coal is the 2nd source of primary energy worldwide, being 30.3% in 2011, beaten only by oil with 33.1%.

So, recognizing environmental impact of using fossil fuels, for coal has most importance the management of its combustion products.

And if for gas this management is in a period of innovation and research, for solids the basic solution is its landfill.

This paper seeks to show that there are other approaches.

It refers existing experiences, good practices and challenges.

It demonstrates also the economic advantages of coal combustion products (CCP) utilisation.

The proposed methodology has a sequence that is based on scenarios of global or European level, to the national reality.

Text development follows the production chain:
– The coal
– The electricity
– CCP utilisation vs landfill

Common within all the chapters is the 3R rule, which generally is applied to deal with the waste problem:
Reduce, showing the solutions corresponding to better performance;
Reuse, as experienced with bottom ash;
Recycle, with utilisation of products which become raw materials for other processes.

2 – THE COAL

2011 coal proven reserves [1] were sufficient to meet consumption for 112 years, so the most abundant fossil fuel, considering the ratio reserve/consumption.

This ratio is 54,2 years to oil and 63,6 years for natural gas.

For the whole European Union has been observed a decreasing trend in the consumption of different types of coal, as can be seen by consulting Eurostat databases.

This reduction is contradicted in the last 2 years, 2010 and 2011, where there is an increased consumption.

This fact is attributed to competitiveness price with other fuels and the increased use of coal in electricity production in some countries as Germany and Spain.

2.1 - Coal consumption in Portugal

The share of coal in primary energy consumption can be seen in the statistics of the Directorate General for Energy and Geology (DGE) [Table 1].
Table 1 – Primary energy consumption

<table>
<thead>
<tr>
<th>Year</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>3,310</td>
<td>2,883</td>
<td>2,526</td>
<td>2,858</td>
<td>1,657</td>
<td>2,406</td>
</tr>
<tr>
<td>Oil</td>
<td>14,305</td>
<td>13,567</td>
<td>12,612</td>
<td>11,765</td>
<td>11,245</td>
<td>10,381</td>
</tr>
<tr>
<td>Natural gas</td>
<td>3,195</td>
<td>3,821</td>
<td>4,157</td>
<td>4,233</td>
<td>4,607</td>
<td>4,475</td>
</tr>
<tr>
<td>Net electricity import</td>
<td>468</td>
<td>444</td>
<td>381</td>
<td>411</td>
<td>226</td>
<td>242</td>
</tr>
<tr>
<td>Renewables</td>
<td>4,267</td>
<td>4,436</td>
<td>4,333</td>
<td>4,833</td>
<td>5,280</td>
<td>5,353</td>
</tr>
<tr>
<td>Industrial waste</td>
<td>26</td>
<td>25</td>
<td>40</td>
<td>40</td>
<td>39</td>
<td>40</td>
</tr>
<tr>
<td>Primary Energy consumption</td>
<td>25,971</td>
<td>25,350</td>
<td>24,462</td>
<td>24,139</td>
<td>22,902</td>
<td>22,675</td>
</tr>
</tbody>
</table>

Last years, oil is less and less used in electricity generation and renewable raises powered by wind mills. [Fig. 1]. Domestics use more natural gas, so coal becomes a backup energy. In dry years, like 2011 or 2012, coal consumption is increasing.

In industry there were 3 main sectors using coal:
- Steel, in the past, now converted to electric ovens. [Fig. 2].
- Cement industry that alternates coal with pet coke, according their prices.
- Electricity generation, which represents the main coal consumption.

There are two coal power plants now operating in Portugal, described with data available by the owners [Tables 2 and 3].

Sines [Fig. 3]

![Figure 3 – Sines power plant (Photo: EDP)](image)

Table 2 – Sines main characteristics

<table>
<thead>
<tr>
<th>Owner</th>
<th>EDP Gestão da Produção de Energia, SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place</td>
<td>Sines</td>
</tr>
<tr>
<td>Start up date</td>
<td>1985, 1.st unit; 1989, last unit</td>
</tr>
<tr>
<td>Net power</td>
<td>1180 MW</td>
</tr>
<tr>
<td>Units</td>
<td>4</td>
</tr>
</tbody>
</table>

Pego [Fig. 4]

![Figure 4 – Pego power plant (Photo: Tejo Energia)](image)

Table 3 – Pego main characteristics

<table>
<thead>
<tr>
<th>Owner</th>
<th>Tejo Energia, SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place</td>
<td>Abrantes</td>
</tr>
<tr>
<td>Start up date</td>
<td>1993, 1.st unit; 1995, 2.nd unit</td>
</tr>
<tr>
<td>Net power</td>
<td>576 MW</td>
</tr>
<tr>
<td>Units</td>
<td>2</td>
</tr>
</tbody>
</table>
2.2 – Coal production in Portugal

DGEG statistics, [Table 4] present coal as an homeland energetic resource, until the end of 1994.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>110</td>
<td>111</td>
<td>91</td>
<td>81</td>
<td>60</td>
<td>0</td>
</tr>
</tbody>
</table>

These reserves, that were available in the past, were important in energy fuel supply and had a role in the electricity sector history.

3 – THE ELECTRICITY

Next approach of electricity sector in Portugal includes the market, coal power plants and environmental issues of these facilities.

3.1 – Electricity in open market

Accomplishing with European Directives, electric system becomes an open market since 2007, when the main national generation operator accepted power purchasing agreements termination.

Their replacement allows that operator to sell electricity in the Iberian Electricity Market (MIBEL), short and long term (OMEL and OMIP, respectively).

There are other trading mechanisms as auctions and direct contracts.

Market organization has now new players, the traders.

They buy electricity from producers and sell it to consumers, using network infrastructures.

When supply meets demand, cheaper units are the first to operate in diagram baseload, and more expensive ones cover peakload consumption.

This is a mechanism similar to generation economic dispatching, made by marginal costs.

3.2 - The role of coal plants

Coal power plants, Sines [2] and Pego, used to work in baseload supply diagram, according their low production cost, having great importance in diversifying primary energy sources [Fig. 5].

Table 5 – Coal power plants generation (Fonte: REN)

<table>
<thead>
<tr>
<th>Generation</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sines (GWh)</td>
<td>9 590</td>
<td>9 694</td>
<td>8 048</td>
<td>6 926</td>
<td>8 869</td>
<td>4 889</td>
<td>6 879</td>
</tr>
<tr>
<td>Pego (GWh)</td>
<td>4 701</td>
<td>4 376</td>
<td>3 615</td>
<td>3 498</td>
<td>3 073</td>
<td>1 663</td>
<td>2 250</td>
</tr>
<tr>
<td>TOTAL (GWh)</td>
<td>14 291</td>
<td>14 070</td>
<td>11 663</td>
<td>10 423</td>
<td>11 942</td>
<td>6 553</td>
<td>9 128</td>
</tr>
<tr>
<td>Consumption (GWh)</td>
<td>47 940</td>
<td>49 174</td>
<td>50 059</td>
<td>50 595</td>
<td>49 873</td>
<td>52 198</td>
<td>50 503</td>
</tr>
<tr>
<td>% of coal</td>
<td>29.8</td>
<td>28.6</td>
<td>23.3</td>
<td>20.6</td>
<td>23.9</td>
<td>12.6</td>
<td>18.1</td>
</tr>
</tbody>
</table>

2008 was affected by the unavailability resultant of the installation desulfurization equipment.

In the future, coal plants may have a more stabilised operation, increasing the share of hydropower with pumping or, if renewable energy keeps rising, can definitely be sent to inactivity.

Of course this depends on relative value of production costs between natural gas and coal, but here coal has the advantage.

3.3 – Clean coal technologies

Environmental concerns were considered in Portuguese projects of coal power plants in Sines and Pego. Later they were upgraded with desulfurization and denitification equipments [Fig. 6].
The technologies used in these steam generators leads to the production of three products resulting from the combustion of coal and desulfurization process:

- Fly ash collected in electrostatic precipitators;
- Bottom ash obtained by gravity ashtrays in the boiler;
- FGD gypsum resulting from the capture of sulphur oxides in the gases.

There are deposition areas near the plants to all these products. However, the option is that landfill was the last resort, for economical and environmental reasons.

**Electrostatic precipitators (ESP)**

Particles in the flue gas were always undesirable, for the image of dark smoke out of the chimney, and by its effect on deposition - due to its acidity they "burn" the surfaces where they fall.

To its capture, the electrostatic precipitators are the most widespread technology in modern power stations for its high efficiency (up to 99.5%) and consecrated as a solution. It consists in the installation of polarized plates in smoke circuit which attracts the ionized particles of the ash. With a periodic beating, the particles will drop in a hoppers zone from where they are pneumatically lead to storage silos [Fig. 7].

As ash, before captured, is taken in smoke suspension from the boiler, they are known as fly ash.

**Ashtrays**

In the furnace, there are two types of ash: one that is clinging to the walls of the boiler known as "slag" and another with significant dimensions that, by gravity, fall at the bottom of the furnace – they are known as "bottom ash".

The collection of ashes can be carried out by a dry extraction system, more efficient then wet systems. [3].

This system consists in a collecting belt with the possibility of crushing and grinding the dry bottom ash removed from the boiler.

Mixing it with economizer and air heater ash, may be introduced in the circuit of fly ash, after electrostatic precipitators [Fig. 8].

**Desulfurization**

Sulphur in coal, during the combustion reacts with oxygen, turning into sulphur dioxide, which in contact with water produces sulphuric acid, highly corrosive and responsible for damage, especially in forests zones around thermal power stations.

\[
\begin{align*}
S + O_2 & \rightarrow SO_2 \\
2SO_2 + O_2 & \rightarrow 2SO_3 \\
SO_3 + H_2O & \rightarrow H_2SO_4
\end{align*}
\]

Flue-gas desulfurization (FGD), adopted in Portugal plants, is a process using wet limestone and producing gypsum. SO\(_2\) emission values are
kept under 200 mg/Nm$^3$, limit established in Large Combustion Plants Directive (LCPD).

Combustion gases, after ESP, counter flow cross an aqueous suspension of grounded limestone, allowing the absorption of sulphur dioxide [Fig. 9]. Absorber is the name given to the equipment where takes place the neutralization and oxidation reaction:

$$\text{CaCO}_3 + \text{SO}_2 + \frac{1}{2}\text{O}_2 + 2\text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot 2\text{H}_2\text{O} + \text{CO}_2 \ [4]$$

Calcium sulphate (gypsum) needs to be dehydrated to have commercial value. However, its characteristics are identical to those of natural gypsum. [4]

**Denitrification**

Nitrogen oxides (NO$_x$) may be transformed into nitric acid, also responsible for acid rain, but, by itself, cause damage to human health, at the level of the respiratory system.

In order to keep emissions below 200 mg/Nm$^3$, as European directive demands, selective catalytic reduction technology (SCR), must be installed.

For optimum gas temperature, catalyst is installed upstream of the regenerative air heater (RAH) and of the electrostatic precipitator (ESP) [Fig. 10].

In this process, reduction of nitrogen oxides to nitrogen (N$_2$) and water (H$_2$O), is obtained by reaction of NO$_x$ and aqueous ammonia (NH$_3$) in a catalytic bed.

Fly ash contamination with ammonia must be avoided, because it may cause damages to concrete operators.

**Capture and sequestration of CO$_2$**

Greenhouse effect gases are connected to global warming. To reduce their emissions of has become one of the fundamental objectives of environmental policies. CO$_2$ capture and storage is included in new power plants projects. [5].

Technologies tested are:

- post-combustion,
- pre-combustion and
- oxy-combustion.

**4 – CCP UTILISATION**

Products resulting from coal combustion in power plants require special management to prevent its disposal, occupying significant areas at facilities.

Cooperation between producers, cement industry, and concrete manufacturing, has led to sustained solutions and advantageous to all the parties.

However, since their use is made almost exclusively in the construction industry, problems in demand side, have effects in the CCP market.

### 4.1 – European situation

In 2009, about 52 million tons of CCPs were produced in Europe (EU15).

The production in all member states of the European Community (EC) is estimated at about 100 million tonnes.

The overall figures in the EU15 in 2009, are compiled in [6].

Interested to analyze some aspects and trends most relevant [Fig. 11 and 12]:

Since 2003, production of CCP has decreased as result of lower utilisation of coal plants for reasons of lower economic activity (consumption of electricity has been reduced), but also of environmental requests and of the use of renewable energies.

Regarding the use, utilisation has being stable in construction and mining recovery and disposal represents only 6.5% of the produced amount.

For these quantities it is difficult to find a solution due to the lack of market regulatory framework.
Fly ash is used as shown below [Table 7]:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 7 – Fly ash utilisation</strong></td>
<td></td>
</tr>
<tr>
<td><strong>2005-2011 average</strong></td>
<td>%</td>
</tr>
<tr>
<td>Cement industry</td>
<td>22.9</td>
</tr>
<tr>
<td>Concrete addition</td>
<td>72.8</td>
</tr>
<tr>
<td>Landfill</td>
<td>4.2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>100.0</td>
</tr>
</tbody>
</table>

Bottom ash is disposed but sometimes is used as concrete or cement minority constituent. Road construction, is also a solution in the future.

FGD gypsum has a market, in the boards manufacture. Since it is a new product, it is meeting consumers in domestic market or for export. Amounts disposed are kept as temporary storage.

Landfills are becoming without material.

### 4.3 – Landfill

There is however a considerable amount of ash that had no commercial output and are disposed in landfills by the plants.

- Main reasons why ash are deposited:
  - High content of unburned carbon, which happens mainly in start up and the load variations. Values over 7% make ash useless according cement and concrete standards.
  - Bottom ash that have a sandy texture and therefore does not meet fineness requirements. Reactivity is lower than in pozzolanic fly ash.
  - Lower economic activity is also a difficulty to ash sells.

Landfills are not a serious environmental situation, since they meet all legal requirements and therefore are the safest way to store these materials.

Bottom areas have waterproofed treatment and materials are the compacted, topsoil covered, after side slope control. Native species of forest are planted over. Water lines must have special care. Control points avoid leachate contamination.

In Portugal there are currently three locations of disposed CCP:

1) EDP Production Sines power plant, has a landfill with up to 200 000 t without tree covering.

2) Pego plant, belonging to Tejo Energia, has mainly disposed bottom ash that could exceed the amount of 100 000 t, with quality for possible future use.

3) Old plant of Tapada do Outeiro, owned by REN and closed since 2004, has an ash landfill with over one million tons.

### 4.2 – Portuguese situation

Published data and estimated values are used to characterize national CCP situation [Table 6].

Table 6 – CCP production in Portugal

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash (t)</td>
<td>398 959</td>
<td>383 935</td>
<td>466 289</td>
<td>241 625</td>
<td>310 935</td>
</tr>
<tr>
<td>Bottom ash (t)</td>
<td>49 707</td>
<td>46 657</td>
<td>49 416</td>
<td>33 772</td>
<td>35 035</td>
</tr>
<tr>
<td>FGD Gypsum (t)</td>
<td>7 536</td>
<td>147 345</td>
<td>241 156</td>
<td>133 221</td>
<td>170 132</td>
</tr>
<tr>
<td><strong>TOTAL (t)</strong></td>
<td>456 202</td>
<td>577 941</td>
<td>756 861</td>
<td>410 622</td>
<td>516 102</td>
</tr>
</tbody>
</table>

Plaster produced amounts [Fig. 13] are the result of new desulfurization facilities in different European countries. The production rises in a very significant way, since the year 2000, in bituminous or lignite coal plants.
Packing and stabilization works have been done [Fig. 14]. A new motorway crossed the disposal area and some amount of ash had to be removed to a non-hazardous waste landfill.

Figure 14 – Tapada do Outeiro landfill
(Photo owned by the author)

4.4 – Main applications

Cement and concrete industry

Portugal follows European practice for ash management. A state intervention, in the past, obliged cement industries to use ash in their manufacturing. [7]

In pozzolanic cements, until 50% of ash can be used as raw material, conferring special features to concretes that use them.

In this framework, fly ash was used in important Portuguese public works. Some examples:
- Blocks in port of Sines pier, headquarters of CGD bank, Via do Infante highway, Oporto underground;
- 2004 European Football Championship stadiums;
- Vasco da Gama Bridge [Fig. 15], Lezíria Bridge, new hydroelectric dams

Concrete industry uses fly ash as an additive. Fly ash allows special properties and features to concrete:
- Progression of strength for a longer period;
- Good performance in hazardous environments;
- High compactness and tightness;
- Gains on workability and conditions of application, either in pumping, whether in compression;
- Reduced need for water, in mixing.

Project managers include ash in specifications for many purposes.

Geotechnical [8]

Some amounts of ash in landfill can be reused. Geotechnical works may need large quantities, paying a low cost.

This is the case of road construction, where fly ash and bottom are particularly suitable as filler in bases and sub-bases of the pavement [Fig. 16].

Ash utilisation is foreseen in "Tender Specifications for Road Constructions" of national road company

Figure 16 – Road construction in Sines
(Photo owned by the author)

Main properties:
- Hydraulic characteristics [9]

Hydraulic binders standards cover these applications: EN 14227-1, 3, 4 and 5.

- Mechanical characteristics [10]

Mechanical behaviour of the materials tested in this type of construction is suitable when compared to natural aggregates.

Moreover, its implementation does not require a specific construction process, being able to be applied by traditional processes.

- Technical and environmental framework

The perception of the environmental benefits of material recovery and reuse is creating a favourable framework for the use as raw material of products resulting from industrial activity. [11]

In current times, all cost reduction factors become important. The use of alternative materials, proven quality, is a factor that increases
competitiveness for companies that are willing to play a role in innovation.

**Gypsum**

Desulfurization systems, installed in Portugal since 2007/2008, raised the problem of finding an output for gypsum.

In the year 2011 about 170000 t were produced. As initially there was no distribution chain through the industries that used natural gypsum as the raw material, disposal areas were foreseen [Fig. 17].

![Figure 17 – FGD Gypsum landfill preparation](Photo by the author)

But major consumers agreed to use FGD gypsum in some utilisations:
- Plaster boards
- Cement retarder
- Self levelling floor screeds
- Gypsum blocks

Two handicaps for Portuguese market:
- Spain is one of the largest natural gypsum European producers pressing national market.
- Several European countries had now desulfurization facilities, which led to high international competition.

Favourable factors were also found and prevailed:
- Produced gypsum proved to have excellent quality.
- The domestic market of plasterboard was in development.

Well succeeded export sales make gypsum landfill to be empty.

In the future it is expected to raise the quantities in cement and mortar industries and for projection plaster.

### 4.5 – CCP Management

CCP issues are different in a power plant and require some technical expertise of those who are involved.

Some problems are really specific and only experience can help to deal with them.

Next, two examples of these kind of issues and how to deal with them.

**Standardisation**

Ash certification according European standards is very important since ash is to be used in cement and concrete, which are subject to very detailed regulations, standards and specifications.

For FGD gypsum, it is important to accomplish with Eurogypsum requirements.

Thus steam generators and process control systems are exploited in order to produce fly ash in accordance with EN 450 "Fly ash for concrete".

In Portugal, since 2006 fly ash, is certified and have CE mark, which is necessary to cross-border selling, in Europe. This means Portuguese ash can be sold in any European country.

**CCP classification**

Currently there are legal mechanisms allowing waste listed materials to be considered as raw materials or by-products.

Fly ash in concrete and cement, a few years ago was covered by this mechanism.

Also FGD gypsum was included for plaster and laminated boards.

Criteria to be met are clear and included in art. 5 of the Waste Framework Directive [12]:
- A guarantee of its future use;
- The possibility of direct use without further processing;
- Being part of a production process;
- Utilisation accomplishes with environmental and health legislation, without adverse impacts.

About this issue, industry associations, ECOBA and EUROELECTRIC, have a position, clarifying this interpretation [Fig. 18]:

![Figure 18 – Classification criteria](Fonte: ECOBA)

Environmental authorities are also attentive to the market of these materials.
4.6 – Economic evaluation of CCP utilisation

Technical and environmental approaches in CCP management must be completed with its economic value verification.

Methodology proposal
This analysis will use methodology common to evaluate projects in the energy sector, particularly in energy savings and increased efficiency.

Investments are evaluated by extra costs of compared solutions and differences in operating costs, comparing them with benefits of additional billing or savings.

Model and assumptions
Description of the installation of the initial solution:
- No storage silos,
- With licensed landfill,
- Disposed material,
- Landfill is closed after 30 years of operation.

New framework:
- Construction of 2 loading silos
- With licensed landfill,
- Overall utilisation rate of 80%, with material sales,
- Landfill is closed after 30 years of operation.

Table 8 shows typical values in a 450 MW power plant, 70% full utilisation, normal scenario to apply project evaluation.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage silos [€]</td>
<td>0</td>
<td>20 000 000</td>
<td>1 000 000</td>
<td>120 000</td>
<td>17 000</td>
<td>50 000</td>
<td>187 000</td>
<td>149 600</td>
</tr>
<tr>
<td>Landfill [€]</td>
<td>10 000 000</td>
<td>4 000 000</td>
<td>6 000 000</td>
<td>2 000 000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional investment [€]</td>
<td>-14 000 000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closing landfill after 30 years [€]</td>
<td>3 000 000</td>
<td>1 000 000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9 quantify solutions according to estimated values obtained from the current market practice.

### Evaluation criteria
3 most common criteria are applied to project cash flow:

- **NPV** – Net Present Value: Sum of present annual cash-flow.

\[
NPV = \sum_{k=0}^{n} \frac{CF_k}{(1+a)^k}
\]  

where:
- CFk – Net Cash Flow, year k
- a – Discount rate
- k – Number of periods
- n – 30 years

- **IRR** – Internal Revenue Rate: Discount rate to NPV=0.

\[
NPV = \sum_{k=0}^{n} \frac{CF_k}{(1+a)^k} = 0, \text{ with } IRR = a
\]

- **PP** – Payback Period: Number of years to cash flow sum be positive.

#### Evaluated Scenarios
From a base scenario, according to the above assumptions, sensitivity analysis for two scenarios is made:

- Scenario 1 - With plant utilisation reduced 50% after year 20. It is the result of loss of competitiveness of the plant.
- Scenario 2 - 50% of price reduction, after year 10. It happens in general crisis and falling demand.

Both alternative scenarios are more onerous than the original, but practice shows that they have some support in equipment obsolescence and shrinkage in the market.

Table 10 shows, for the initial setting, the “cash flow” to apply the above criteria.
Applying the financial evaluation criteria, the results are in Table 11.

Table 11 – Economic indicators

<table>
<thead>
<tr>
<th></th>
<th>Base scenario</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV [€]</td>
<td>18 197 878</td>
<td>16 151 867</td>
<td>11 734 684</td>
</tr>
<tr>
<td>IRR [%]</td>
<td>20.2</td>
<td>20.0</td>
<td>18.4</td>
</tr>
<tr>
<td>PP [years]</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Even in the worst case, investment in use of CCP appears to be very attractive and with the possibility of being recovered in the initial years. In this case, Payback period is not changed because scenarios only differ after 10 years.

The discount rate, 8%, could to be higher and the investment still profitable, since the IRR is around 20%.

5 - Conclusion

Coal is important to security of energy supply (coal has the largest reserves in the world), to diversify energy sources, to use local resources, where is available and to have a generation in a low price.

However, environmental issues have to be considered in coal use.

Based on the directives and regulations that affect energy generation in European Union member states - and therefore also the production of PCC - energy industry must make efforts to always provide good quality products to the construction market.

The case of fly ash and gypsum suggests that, this is possible, if favorable factors are verified.

From environmental point of view, this policy means to save energy and natural resources, so emissions reduction.

Certification and compliance with legal requirements is the key to success in the industry.

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