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Environmental Impact Assessment of GHG Emissions Generated by Coal Life Cycle and Solutions for Reducing CO_2

Cristian Dincă[1], Călin-Cristian Cormoş[2], Horia Necula[1]

[1]Power Plant Department, University Politehnica Bucharest, Bucharest, Romania; [2]Facultatea de Chimieşi de Inginerie Chimică, Universitatea Babeş-Bolyai, Cluj-Napoca, Romania.
Email: crisflor75@yahoo.com, cormos@chem.ubbcluj.ro, horia@energ.pub.ro

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ABSTRACT

The objective of this paper consists of evaluating the coal life cycle and proposing technical solutions for reducing GHG emissions. After applying the life cycle assessment on the coal life cycle, it was noticed that the power engineering stage has a bigger environmental impact on different indicator impacts. In order to reduce the GHG emissions the CO_2 chemical absorption process was integrated in the power plant based on the circulating fluidized bed combustion technology. Two cases were analyzed: super-critical and ultra-supra-critical parameters. For each case the environmental indicators (global warming potential, abiotic depletion potential, human toxicity potential, photochemical potential, acidification potential, eutrophisation potential) were evaluated in order to estimate the environmental effects on the coal life cycle with CO_2 capture process. After the integration of the CO_2 capture post-combustion process into the power plant, the GHG emissions decreased from 450,760 CO_2 equiv. tons to 75,937 CO_2 equiv. tons for super-critical parameters and from 438122 CO_2 equiv. tons to 73245 CO_2 equiv. tons for ultra-supra-critical parameters respectively. In order to increase the absorption capacity of the MEA solvent the SO_2 emissions were reduced from flue gases and consequently the acidification potential was reduced too in both cases. On the contrary, the amount of fuel increased in order to maintain the functional unit as a result of the efficiency penalty of the CO_2 capture integration in the power plant.

Keywords: CO_2 Capture; Coal; LCA; Amines

1. Introduction

The coal is nowadays one of the main primary energies which the energy sector uses for covering the electricity demand. However, despite the fact that it is attracttive for the energy sector, the coal combustion poses some environmental issues. According to latest data, the reserve reported to production (R/P) ratios vary significantly [1]: for oil it is about 45.7 years, for natural gas 62.8 years and for coal 119 years. Coal is in the best position as it gives the longest energy independence, and its reserves are more uniformly spread, which makes the world market more stable and prices are not so volatile. The concerning aspects linked with coal usage in the energy sector are CO_2 emissions. For example, for the generation of one MWh of electricity, the CO_2 emission in the case of natural gas is about 350 - 400 kg, and in the case of the coal is about 800 - 900 kg [2]. The continuation of coal usage for power generation is sustainable only if CO_2 is captured and then safely stored for a long time.

The need to increase the security of primary energy sources and to reduce CO_2 emissions, leads to the large scale utilization of renewable energy sources (solar, wind, tides, biomass etc.) at a large scale. In this context, the European Commission has set a target for the EU that until 2020, 20% of the whole energy mix should be covered by renewable energy sources as well as that there should be a 20% cut of CO_2 emissions compared with 1990 levels [3]. Furthermore, the European Union is prepared to cut 30% of CO_2 emissions by 2020 if other developed countries proceed to similar cuts. Along this line, Romania has a significant potential of renewable energy sources, just to mention the ones related to this project proposal various biomass sorts (e.g. sawdust, agricultural wastes, etc.). Regarding the environmental protection and the mitigation of climate change, the reports of Intergovernmental Panel on Climate Change—IPCC [4] established on scientific basis that the climate change and the rise of global temperature levels noticed over the past 50 years are linked with human activity and associated with greenhouse gas emissions (mainly CO_2). According to IPCC statistics, the sectors that generate the highest CO_2 emissions are: the power generation (21.3%), the industrial sector (16.8%) and the transport sector (14.0%). These constantly increasing greenhouse gas emissions are responsible for an increase in temperatures, which is expected to continue over the coming decades to reach up to +1.4˚ to +5.8˚C globally by the year 2100 (compared with 1990 temperatures). Temperature increases are causing severe droughts in some parts of the world and extreme weather conditions. One main target related to the limitation of global warming is to take serious actions to limit the global average temperature increase to 2˚C compared with preindustrial levels. Research shows that stabilizing the level of greenhouse gases at 450 ppm would lead to a 1 in 2 chances to reach the target of 2˚C compared with a 1 in 6 chance if levels reach 550 ppm and a 1 in 16 chance if the level hits 650 ppm. In terms of reducing greenhouse gas emissions this means that the global emissions must fall by almost 50% compared with 1990 levels by 2050, which implies a 60 to 80% reduction for developed countries [5].

In order to mitigate the climate change, a special attention is given to the reduction of CO_2 emissions by means of capture and storage (CCS) techniques. When it comes to CO_2 capture, there are several options: post-combustion capture, pre-combustion capture, oxy-combustion or different emerging new technologies which are very promising in terms of reducing CO_2 capture penalties e.g. chemical looping, polymeric membranes, enzymatic systems etc. [6,7]. Some of the potential industries with significant CO_2 reduction capabilities considering stationary sources are: power generation and some industrial sectors having large energy consumptions (e.g. cement, metallurgy, chemical, pulp and paper etc.).

Over the last period, several scientific papers have analyzed different power generation technologies based on coal using the life cycle assessment [8-19]. The scientific analyses focused on CO_2 capture post and oxy combustion technology integration in the energy power plants [8,9]. Also, other authors have developed and adapted the life cycle assessment methodology by integrating CCS technology in the energy units [10,11]. Kather *et al*. and Husebye *et al*. studied the technical and economic effects of the capture, transport and storage technology integration in the pulverized coal combustion power plant [12,13]. In another paper the authors developed a database on the emissions generated in the power plant stage, and they determined the stripper performance in terms of energy [14]. In the same vein, in the paper of Jassim *et al*., the authors have created an absorber/stripper model [15]. Lawal *et al*. have elaborated a model based on CO_2 capture integration in the coal fired power plant at a demonstrative scale [16].

However, these works are focused on assessing emissions of greenhouse gases in the stage of converting coal into electricity. Just a few scientific papers take into consideration all the coal life cycle stages but without tacking in consideration energy production using the circulating fluidized bed coal combustion technology. Therefore, this paper is intended to assess the environmental impact considering the coal life cycle by integrating the circulating fluidized bed combustion equipped with CO_2 capture by chemical absorption unit.

In this paper we analyzed the coal life cycle energy with power generation in a circulating fluidized bed combustion technology. The inventory and the impact assessment were based on the life cycle analysis methodology and on the CML methodology proposed by the University of Leiden (Netherlands) [17]. In this analysis, we have identified all the greenhouse gases throughout the coal life cycle (extraction, treatment, transport and combustion stage) and we specified the contribution of every gas to the total CO_2 equivalent.

2. Material and Methods

2.1. Life Cycle Assessment Methodology

In this paper we used the life cycle methodology in order to evaluate the GHG emissions generated by the entire coal life cycle. The life cycle assessment permits identifying and quantifying all the greenhouses gases generated throughout the entire coal life cycle. According to ISO, the LCA methodology consists in four steps: Goal and Scope, Life Cycle Inventory (LCI) analysis, Life Cycle Impact Assessment (LCIA) and Interpretation [17].

2.2. Definition of Scope and Goal

The objective of the paper consists in evaluating the greenhouses gases generated by the coal life cycle in the followings stages: coal extraction, coal treatment, coal transport and coal combustion for electricity generation. The environmental effects on the CO_2 capture chemical absorption process integration in the power plant will be also evaluated.

The paper analyzed two cases concerning the electricity required by the processes before the combustion stage. **Figure 1** presents the coal life cycle in the case when the energy required by every stage is provided by the coal life cycle. M_{cb}^{1}, M_{cb}^{2}, M_{cb}^{3} represent the amount of fuel required by the energy unit in order to provide the electricity for the process. M_{cb}^{ex}, M_{cb}^{tr}, M_{cb}^{tp} represent the amount of raw coal extracted, the amount before the treatment process and the amount of coal that is transported to the consumer.

The efficiency for every process (extraction, treatment and transport) is defined by: η_{ex}, η_{tr}, η_{tp}. E_t is the annual electricity produced by the power plant.

Figure 2 shows the case when the energy required by each of the process above mentioned is generated by the national energy system.

The cases analyzed in this paper are divided in two groups: Case 1 refers to the coal life cycle without CO_2 capture; Case 2 refers to the coal life cycle with CO_2 capture process. In both cases the electricity required by the processes of the coal life cycle (extracting, treatment, transport stage) is provided by the national energy system. The cases are:

- Case 1: Coal life cycle without CO_2 capture section;
- Case 2: Coal life cycle with CO_2 capture section.

In the second case, the energy generated by the national energy system takes into account the primary energy in the mix of national energy. So, the pollutant emission $\left(e_p\right)$ generated by the energy consumed by every process is determined with the relation 1.

$$e_p = \sum_{i=1}^{n} e_p^i \tag{1}$$

where:

e_p^i—pollutant emission according to the primary energy used, *i*, in g/kWh.

The energy needed for the upstream stages of the energy production stage comes from the national power grid and it correspondsto the mix: coal—38%; hydro—27%; nuclear—20%; natural gas—13% petroleum—2% [18].

Figure 3 presents the processes included in the coal life cycle. The power plant is equipped with a CO_2 capture post-combustion system. For the amine regeneration, a steam flow is extracted from the steam turbine, (S).

Legend:

E_e—the electricity consumed in the extraction process, in MWh;

E_{tr}—the electricity consumed in the treatment process, in MWh;

E_{tp}—the electricity consumed in the transport process, in MWh.

2.3. Functional Unit

In this analysis, in order to compare the coal life cycle with and without the CO_2 capture section we have proposed the functional unit: the annual electricity required for a consumer. The electricity required by the consumer $\left(E_c\right)$ from the residential and tertiary sector is:

$$E_c = E_p^y \cdot N_y \tag{2}$$

where:

E_p^y—represents the annual electricity required by a person, in MWh/year/pers;

N_y—the number of persons;

The amount of the fuel necessary to be produced by the electricity unit $\left(E_t\right)$ is:

$$E_t = \frac{E_c}{\eta_e} \tag{3}$$

η_e—represents the efficiency of the electricity distribution process (taking into account the electricity loss), in %.

Table 1 presents all the specific emissions (in gr/kg fuel) generated by the coal life cycle for extraction,

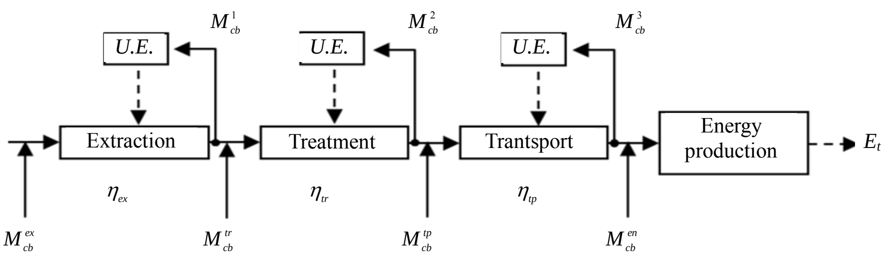

Figure 1. Coal life cycle—Case 1.

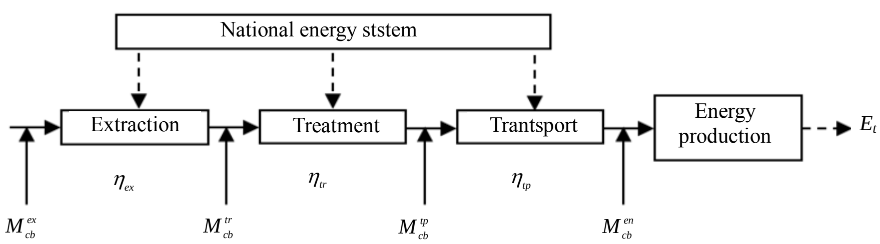

Figure 2. Coal life cycle—Case 2.

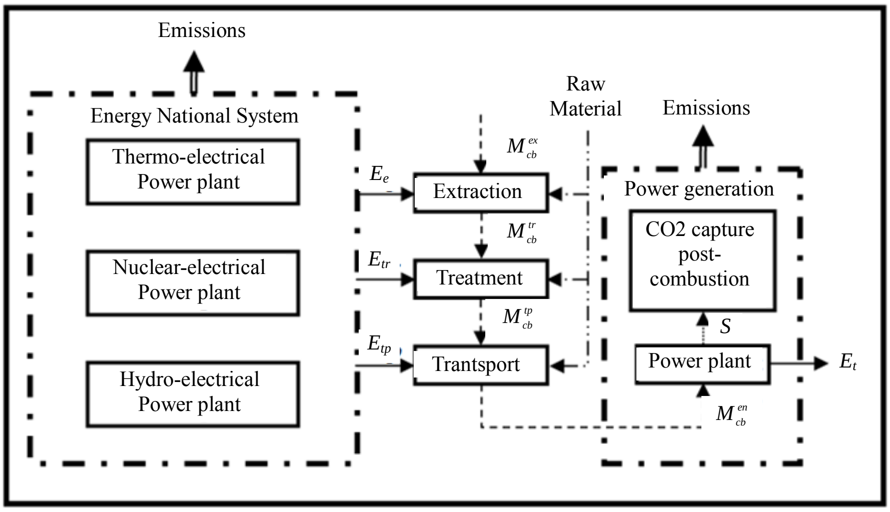

Figure 3. The boundaries of the studied system.

Table 1. The emissions generated by the each stage of the coal life cycle, in gr/kg.

Emission	Extraction	Treatment	Transport	Combustion
NH_3	0.0494	0.0245	2.21×10^{-7}	0.000121
CO_2	3.643	3.74	0.039	1103.187
CO	0.00381	0.00322	0.00322	0.1737
HCl	1.31×10^{-9}	3.05×10^{-9}	3.1×10^{-10}	4.07×10^{-5}
HF	2.43×10^{-9}	5.26×10^{-9}	1.64×10^{-11}	1.96×10^{-6}
H_2S	1.03×10^{-9}	1.12×10^{-9}	6.87×10^{-13}	1.7×10^{-7}
CH_4	0.6391	0.00738	2.04×10^{-6}	9.89×10^{-9}
NO_x	0.0191	0.0173	0.000413	0.00943
N_2O	0.000316	0.000466	5.5×10^{-7}	3.4639
Praf	0.00789	0.00153	4.12×10^{-5}	0.00353
SO_2	0.0412	0.0112	2.13×10^{-4}	10.198
C_6H_6	-	-	-	7.2598

treatment, transport and combustion stage. In order to determine the emissions generated in the energy process for producing the annual electricity $\left(P_{ik\_rec}\right)$, relation 4 is used. All the emissions collected are determined according to the functional unit. As a result, the emissions given in **Table 1** $\left(P_{ik}\right)$ are corrected with the fuel mass $\left(M_{comb}^{i}\right)$ corresponding to the analyzed stage.

$$P_{ik\_rec} = P_{ik} \cdot M_{comb}^{i} \quad (4)$$

2.4. Coal Life Cycle Impact Assessment

The methodology CML was used for quantifying the GHG emissions collected in the inventory analysis. The impact analysis is a methodology where the potential impact of the resource requirements and emissions is classified, characterized and evaluated. The impact assessment includes three steps:

- *Classification*: relates the emissions to the relevant impact categories;
- *Characterization*: quantifies the contribution of emissions to the relevant impact categories (e.g., convert NO_x to SO_2 equivalents);
- *Evaluation*: ranks the relevant impact categories.

Table 2 shows all environmental indicators for energy solutions evaluation.

Figures 4-6 show the climate change impact evaluation for different coal life cycles which takes into account the extraction, treatment, transport and energy generation stages: pulverized coal (sub-critical, supra-critical and ultra-supra-critical parameters); circulating fluidized bed

Table 2. The environmental indicators.

Class impact	Emissions participants	Reference pollutant	Impact scale
Global warming potential (GWP)	CO_2, CH_4, N_2O	CO_2-equiv.	Global
Acidification potential (AP)	SO_x, NO_x, HCl, HF, NH_3	SO_2-equiv.	Regional, local
Eutrophication potential (EP)	NO, NO_2, NH_3, PO_4^{3-}	PO_4^{3-} -equiv.	Local
Photo-oxidant formation potential (POCP)	NMHC	C_2H_6-equiv.	Local
Human toxicity potential (HTP)	Dust, Hg, H_2S, NO_2, NH_3, SO_2	1,4 DCB equiv.	Global, Regional, Local
Abiotic resources depletion potential (ADP)	Coal	Antimoniu eqiv.	Global, Regional, Local

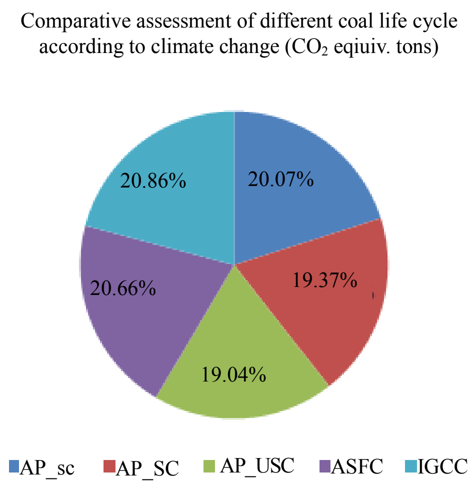

Figure 4. Global comparative assement of different coal life cycles according to theclimate change.

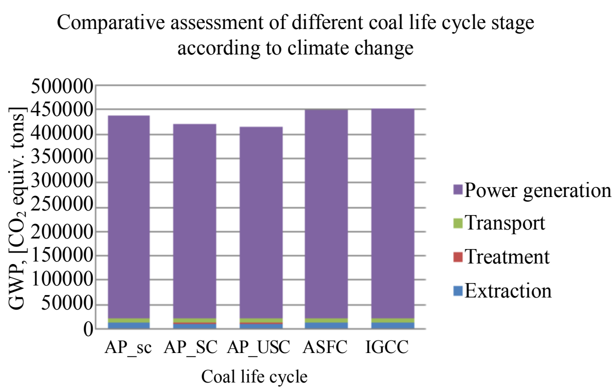

Figure 5. Comparative assessment of different coal life cycle stages according to the climate change.

combustion (ASFC); and integrated gasification combined cycle (IGCC). In addition, the contribution of the coal life cycle stage to the climate is presented. The power generation stage has the highest contribution to the climate change due to the CO_2 emissions generated by coal combustion.

Figure 4 presents a comparison of different coal life cycles with the energy conversion stage. The analysis of different ways to produce the electricity from coal shows

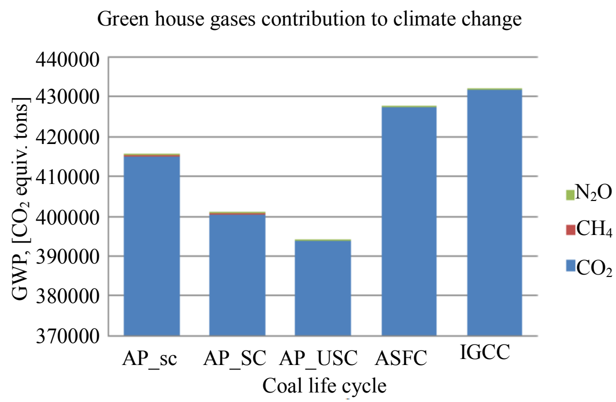

Figure 6. The contribution of green house gases to the climate change power generation stage.

no obvious difference between the GWP impact indicators. But, if we analyze the whole coal life cycle, we notice that the power generation stage has the main contribution to the climate change (>95%) independent of how the energy technology was used.

For the reduction of the environmental impact of the coal life cycle used in the energy sector the integration of the CO_2 capture section is necessary. In **Figures 7-9** the effects on the eutrophisation class impact is presented for the coal life cycle.

The NO_2 and NH_3 are the pollutants that have a contribution to the eutrophisation class. However, the NO_2 is the main pollutant and it is generated in the power generation stage. The NH_3 is generated in the power generation stage as a result of the measures taken to reduce the NO_x emissions.

Figures 10-12 show the impact of the coal life cycles according to POCP. In this case, the IGCC solution has a small impact due to the SO_x desulphurization before syngas combustion.

NO_2 and SO_2 are the pollutants with the main contribution to the POCP. The difference between technologies consists in the measured applied for SO_2 emissions reducetion.

The effects on the environment according to human toxicity of the coal life cycle are presented in **Figures 13-15**.

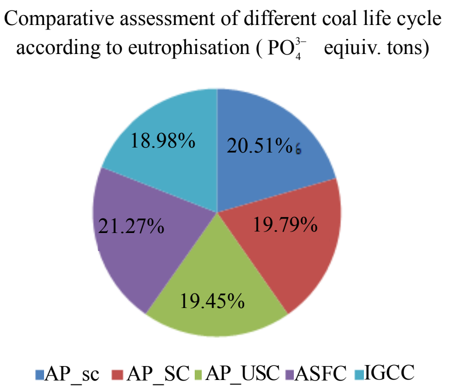

Figure 7. Global comparative assement of different coal life cycles according to the eutrophisation.

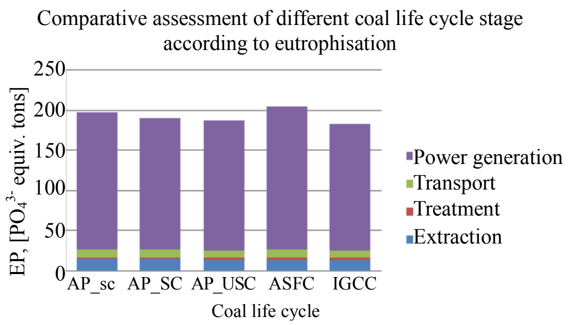

Figure 8. Comparative assessment of different coal life cycle stages according to the eutrophisation.

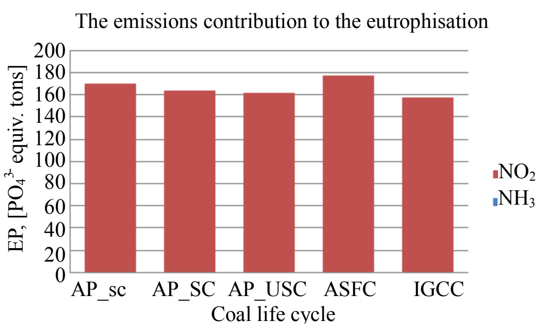

Figure 9. The contribution of the emissions to the eutrophisation.

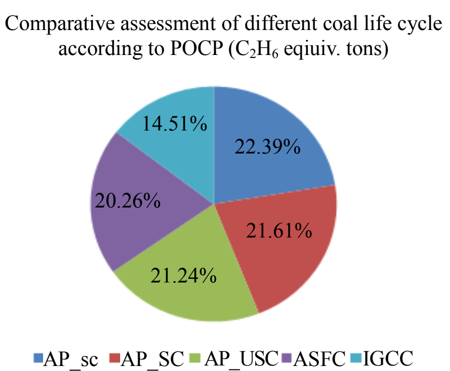

Figure 10. Global comparative assement of different coal life cycle according to POCP.

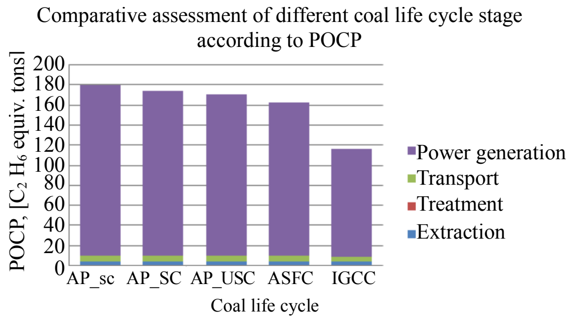

Figure 11. Comparative assessment of different coal life cycle stages according to POCP.

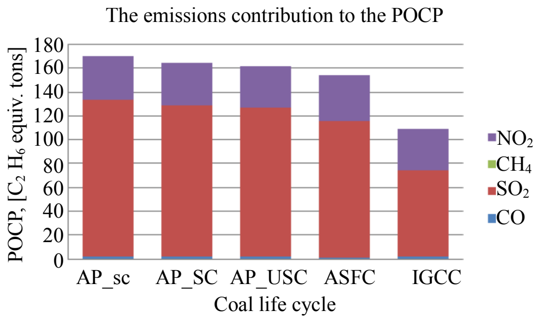

Figure 12. The contribution of the emissions to the POCP.

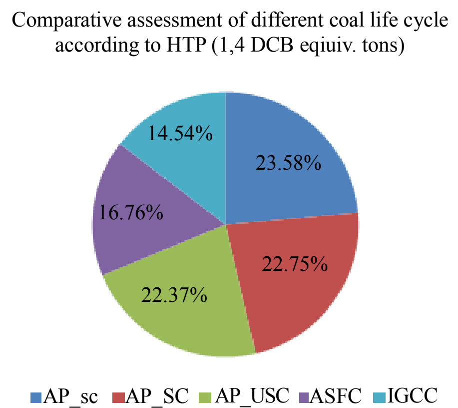

Figure 13. Global comparative assement of different coal life cycles according to HTP.

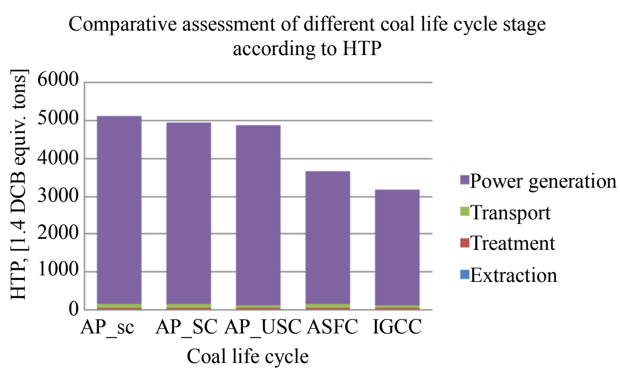

Figure 14. Comparative assessment of different coal life cycle stages according to HTP.

The IGCC and CFBC technology have a small environmental impact considering HTP compared to pulverized coal combustion.

The pollutants that contribute to the human toxicity class are generated mainly during the power generation stage. The other stages of the coal life cycle are a small contribution to this environmental indicator (less than 2%).

The main pollutants that contribute to the human toxicity indicator are dust, NO_2 and SO_2, which are generated mostly in the combustion stage.

Figures 16-18 show the environmental impact of the coal life cycle according to acidification.

Considering the low emissions of SO_2 generated in the combustion stage, IGCC have a small environmental impact. In contrast, the pulverized coal has the biggest environmental impact.

As in the POCP case, the SO_2 emissions have the main contribution, mainly generated during the power generation stage.

In **Figure 19** a comparative assessment between different coal life cycles is presented. In order to produce the energy required by the consumer, the pulverized coal combustion with ultra-supra-critical parameters has the lowest amount of coal compared to other technologies.

Therefore, in order to reduce the GHG emissions we propose to integrate the CO_2 capture section in the circulating fluidized bed combustion and to analyze the global environmental effects.

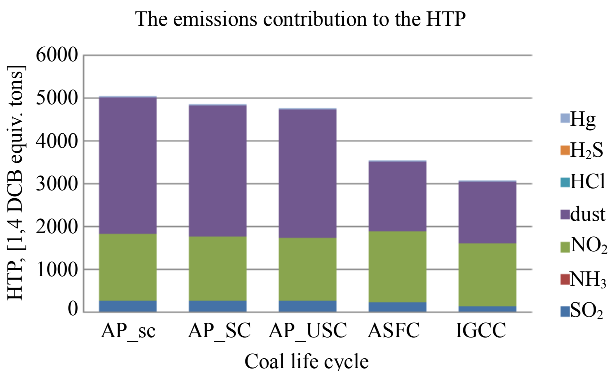

Figure 15. The contribution of the emissions to the HTP.

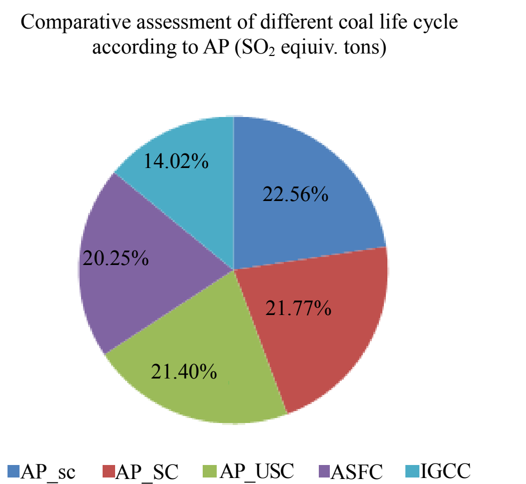

Figure 16. Global comparative assement of different coal life cycles according to AP.

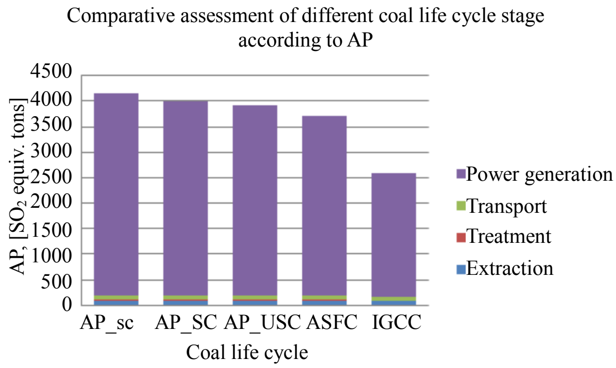

Figure 17. Comparative assessment of different coal life cycle stages according to AP.

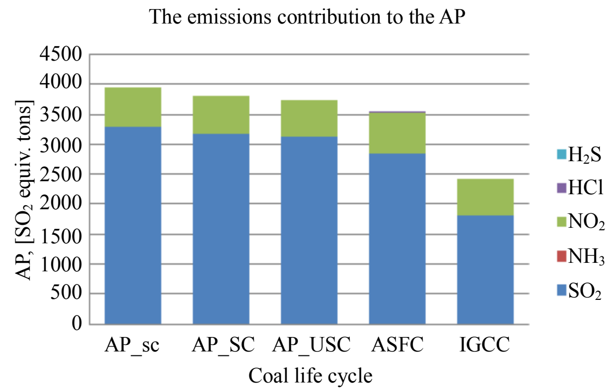

Figure 18. The contribution of the emissions to the AP.

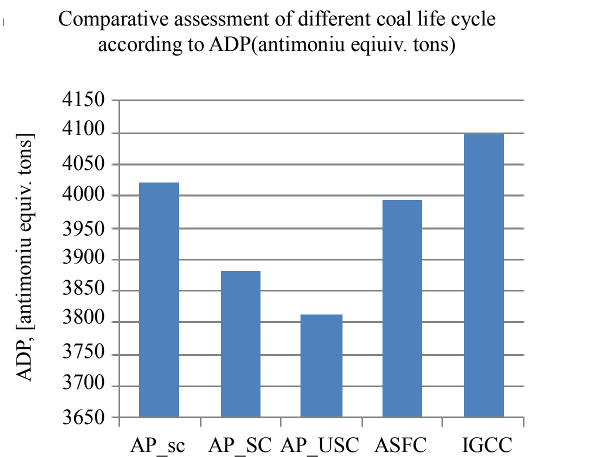

Figure 19. Comparative assement of different coal life cycles according to ADP.

2.5. Circulating Fluidized Bed Combustion with CO_2 Capture

Figure 20 presents the CFBC pilot installation with CO_2 chemical absorption process integration. The CO_2 chemical absorption capture process includes an absorber and a stripper unit. In order to increase the CO_2 capture performance the following process parameters were optimized in this study: MEA absorption capacity, the thermal energy required for solvent regeneration, and the CO_2 capture efficiency. The optimization was performed by varying the lean and rich loading value of solvent. The difference between the last two parameters represents the MEA absorption capacity.

Legend:

Ⓐ—the rich loading solvent after the Absorber unit (measure point);

Ⓑ—the rich loading solvent after the reservoir "MEA rich" (measure point);

Ⓒ—the lean loading solvent after the economizer (measure point);

Ⓓ—the lean loading solvent after the re-boiler unit (measure point);

Ⓔ—the lean loading solvent after the reservoir "MEA lean" (measure point);

Ⓣ—the temperature measure point;

Ⓘ—the electric current intensity measure point;

c.w. —cold water;

—the gas analyzer (TESTO).

Before entering the absorber unit, the flue gases are desulphurized using 1.5% NaOH. The absorber unit is realized by a modern packing design using aRaschig ring with a nominal size of 16 mm [11]. Hence, the absorber column has a number of 8 theoretical stages with the contact surface area of around 120 m^2/m^3.

The coal composition was: C—21.55%; H—1.25%; O—2.55%; N—0.65%; S—1%. For this last analysis of the lignite used, the low heating value 7 543 MJ/kg.

Table 3 shows the range of variation for the process parameters analyzed.

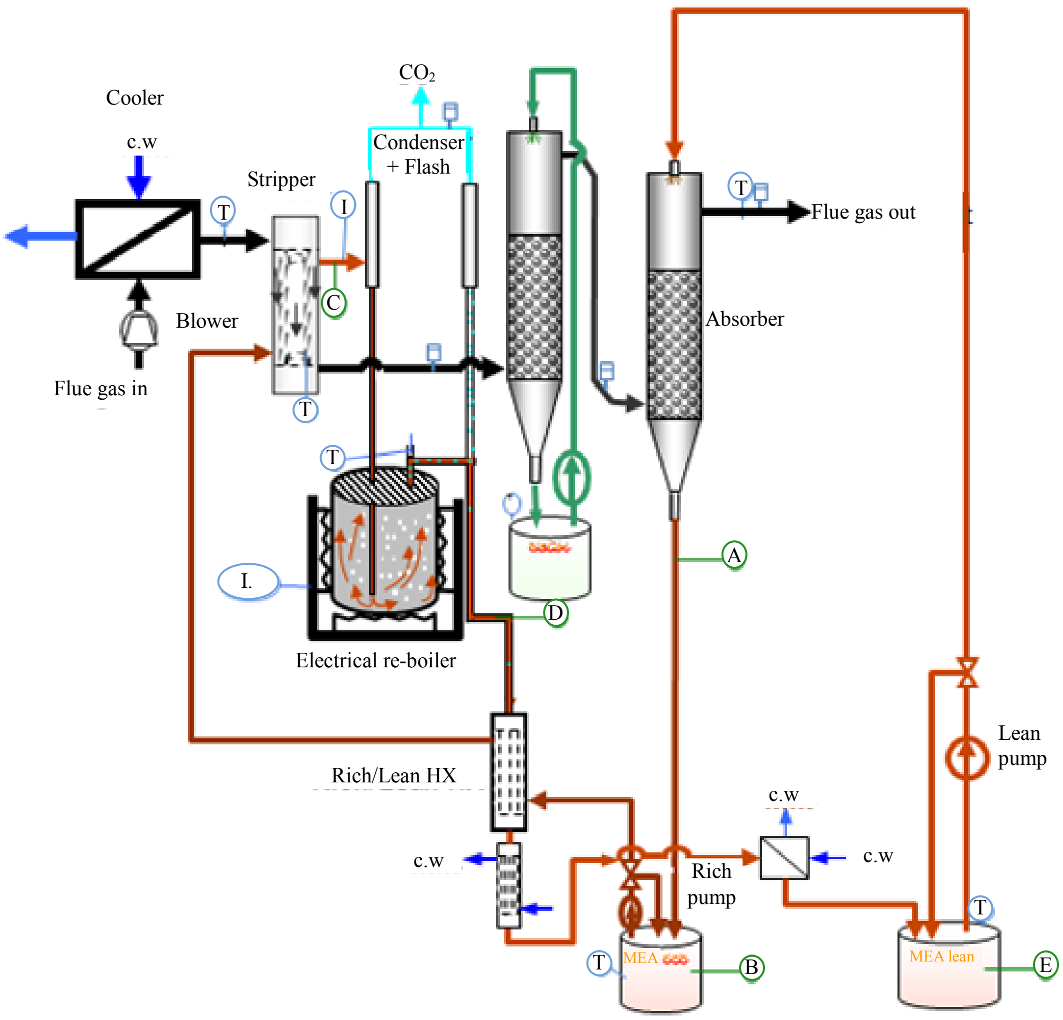

Figure 20. The CO_2 post-combustion section.

Table 3. The range of process parameters.

Process parameter	Range of variation	Process conditions
Solvent flow rate, kg/h	500 - 1800	p_{abs}-ct.; ε_{CO_2} -ct.; C_{MEA}-ct.
CO_2 partial pressure, atm	~0.11	n.a.
Temperature of absorption, ˚C	31 - 49	p_{abs}-ct.; ε_{CO_2} -ct.; C_{MEA}-ct.
Pressure of absorption process, atm	1.1 - 2.1	n.a.
L/G ratio, kg_l/kg_g	0.45 - 1.62	p_{abs}-ct.; ε_{CO_2} -ct.; C_{MEA}-ct.
CO_2 efficiency,%	~90	p_{abs}-ct.; C_{MEA}-ct.
MEA concentration, wt.%	~25	p_{abs}-ct.; ε_{CO_2} -ct.

3. Results and Discussion

The objective of this paper was to ameliorate the environmental impact on the coal life cycle by reducing the GHG emissions generated during the power generation stage. In this respect, we analyzed the integration of the CO_2 post-combustion capture in the circulated fluidized bed combustion. We also, analyzed the effects on the CO_2 capture section integration in the power plant on the environmental impact.

Firstly, the MEA capacity was determined by measureing the lean and rich loading solvent in different points indicated in **Figure 20** [11]. Thus, **Table 4** shows the values determined for the solvent.

As for the absorption capacity of MEA, the results were validated in the similar study [18,19].

Points A, B, C, D, E are indicated in the legend of **Figure 20**. The difference between points A and E represents the absorption capacity of the MEA for 25% wt. concentration in the solvent.

Figure 21 shows the variation of the energy required by the solvent according to the CO_2 capture efficiency for different L/G ratio.

One can notice that for each L/G ratio a minimal value of energy required is obtained for 90% CO_2 capture efficiency. The optimal value for L/G ratio was 0.7 kg_l/kg_g. So, for a flue gas flow (according to coal flow and the excess air) 0.7 kg of liquid solvent is necessary for a CO_2 capture efficiency of 90%. This value for the solvent prevents the metallic surface corrosion by using a higher solvent flow.

Table 5 shows a comparative environmental assessment between a power plant with circulating fluidized bed combustion of coal with and without CO_2 capture for supra-critical and ultra-supra-critical parameters.

After the integration of the CO_2 capture chemical absorption process in the power plant, and for the same functional unit, the GWP impact indicator decreased from 450,760 to 75,937 CO_2 equiv. tons and from 438,122 to 73,245 CO_2 equiv. tons.

But the CO_2 capture process integration in the power plant has reduced the power plant global efficiency with almost 6%, which means that more fuel was needed in order to accomplish the functional unit. However, for a good absorption capacity of the MEA solvent, the flue gas was desulphurized which permitted the considerable reduction of the acidification potential indicators.

4. Conclusions

In this paper the coal life cycle was investigated from the environmental point of view in order to identify the amount of GHG emissions generated. Three energy solutions (pulverized coal with sub-critical, supra-critical and ultra-supra-critical parameters; circulating fluidized bed combustion and integrated gasification with combined cycle) were analyzed and compared from different indicator impacts. The power generation stage has the main contribution to the environmental impact for all the impact indicators analyzed. As for the GHG emissions, the main pollutant is CO_2 for all the energy technologies analyzed. In order to ameliorate the environmental impact of the coal life cycle concerning the GHG emissions, the CO_2 capture by chemical absorption was proposed for the integration in the ASFC technology.

In order to capture the CO_2 the MEA solvent was used (25% wt. in solvent).The MEA absorption capacity was measured in various points of the experimental installation and the procedure was repeated for data validation. The average MEA absorption capacity was 0.07 mol CO_2/ mol MEA. The energy required by the process for the regeneration of the MEA solvent was 2.9 and 2.77 GJ/ tCO_2 captured in the case of supra-critical and ultra-supra-critical parameters. A steam flow was extracted from the low pressure steam turbine (LPST) in order to regenerate the MEA solvent. An energy penalty was 5.94% and 6.4% respectively for both cases.

On the other hand, for the coverage of the functional unit more fuel is needed and in that case one can notice an increase of the abiotic depletion potential with approximately 16% as compare to the power plant without CO_2 capture. In order to reduce the corrosive impact of

Table 4. Lean and rich loadings at the five points of the pilot installation (25% MEA), in (mol CO_2/mol MEA).

Sample	Rich loading solvent			Lean loading solvent	
	A	**B**	**C**	**D**	**E**
1	0.51	0.574	0.52	0.317	0.434
2	0.506	0.568	0.518	0.325	0.429
3	0.503	0.578	0.512	0.318	0.444
4	0.521	0.584	0.518	0.314	0.438
5	0.517	0.569	0.517	0.324	0.432
6	0.501	0.567	0.524	0.319	0.429
7	0.497	0.566	0.513	0.32	0.421
8	0.489	0.571	0.509	0.317	0.43
9	0.502	0.575	0.511	0.318	0.433
Average	**0.505**	**0.572**	**0.515**	**0.319**	**0.432**

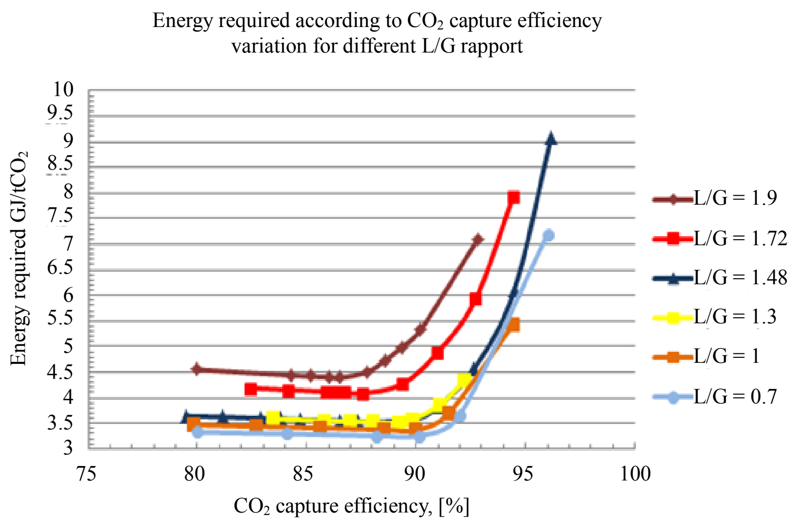

Figure 21. The optimal value of the energy required according to the CO_2 capture efficiency and L/G rapport.

Table 5. Comparative assessment between the power plants with and without CO_2 capture.

Process Parameter	Power plant without CO_2 capture		Power plant with CO_2 capture	
	A	B	A	B
Steam cycle parameters				
Functional unit, MWh	420000	420000	420000	420000
CO_2 removal steam generator output, kW	-	-	38550	39889
Heat consumed for main steam, kW	649265	623025	649265	623025
CO_2 *removal system parameters*				
MEA solvent concentration,%	-	-	25	25
Solvent regeneration energy, GJ/tonneCO_2	-	-	2.9	2.77
Steam flow in the LPST, kg/s	185.02	179.04	119.89	116.02
Steam extraction flow for MEA regeneration, kg/s	-	-	65.13	63.02
Plant performance parameter				
Net plant efficiency,%	46.21	48.15	40.27	41.75
Energy penalty,%	-	-	5.94	6.4
Environment indicator				
ADP, antimony equiv. tons	3994	3890	4651.6	4486.7
GWP, CO_2 equiv. tons	450760	438122	75937	73245
POCP, C_2H_6 equiv. tons	163.18	158.61	63.48	61.23
HTP, 1,4 DCB equiv. tons	3655.7	3553.2	3996.1	3854.5
AP, SO_2 equiv. tons	3728.6	3624.1	1179.3	1137.5
EP, PO_4^{3-} equiv. tons	205.21	199.45	238.49	230.03

the MEA used, in this study it is obtained an L/G optimal ratio. Thus, a small amount of MEA solvent is used for the same amount of thermal energy used by the process. By tacking in account the CO_2 capture efficiency and the minimal value for energy required by the process, the L/G optimum was obtained 0.7 kg_l/kg_{fg}.

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