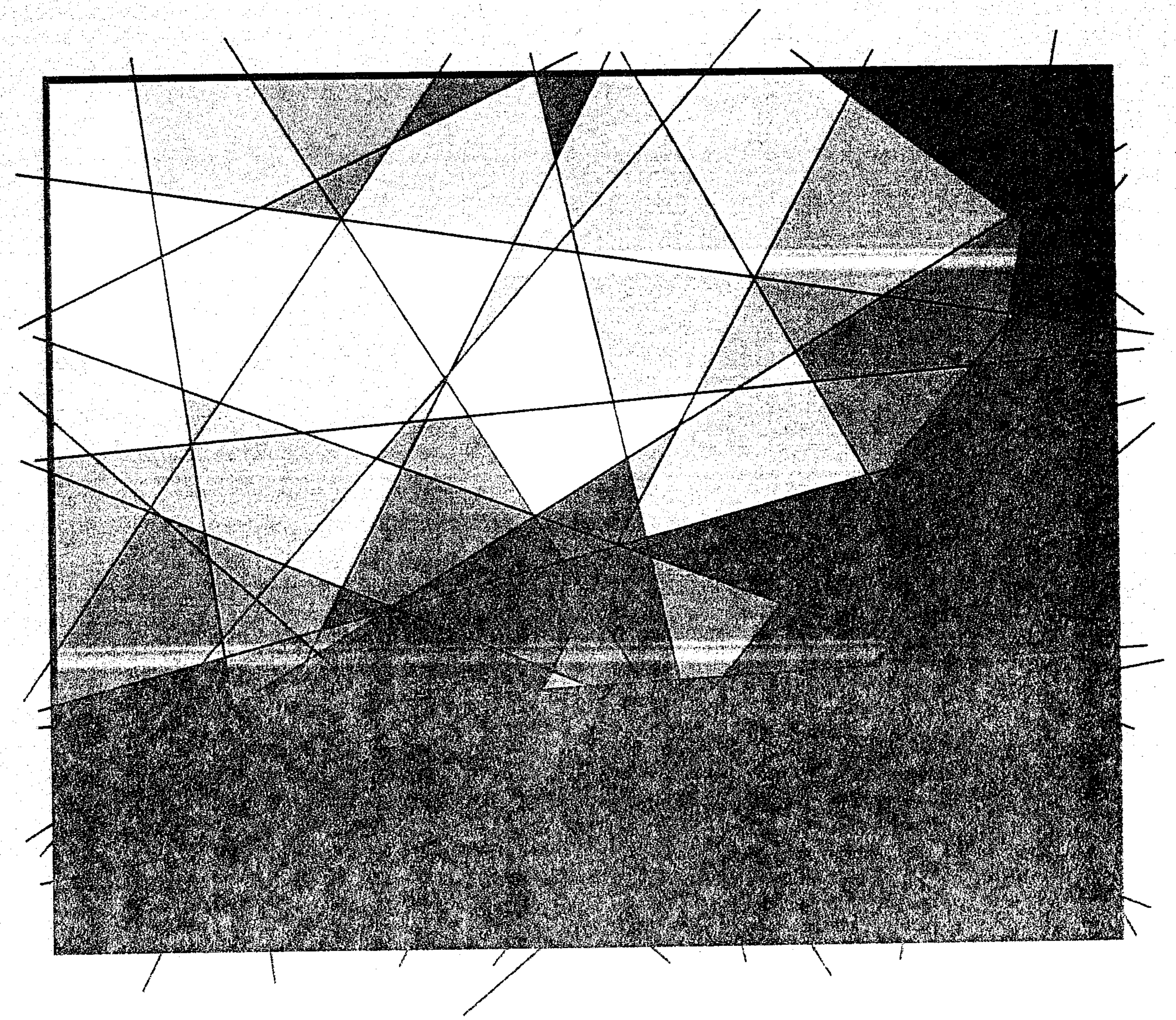
INTERNATIONAL ENVIRONMENTAL LAW: CONTEMPORARY CONCERNS AND CHALLENGES IN 2014

Edited by Vasilka Sancin and Maša Kovič Dine



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SUSTAINABLE ENERGY PRODUCTION FROM OLD COAL-FIRED THERMAL POWER PLANTS BEYOND 2016 UTILIZING MAJOR REHABILITATION PROGRAM

Vlatko Cingoski*, Dimitar Tanurkov†, Kosta Papasterevski‡,

ABSTRACT

Due to its natural abundance and proven exploitation history, coal still represents an important fuel resource for electricity production worldwide. However, as a result of its unfavourable environmental impact and negative emission footprint, recently, a lot of efforts have been taken to provide more "*environment friendly*" energy production burning coal, such as Carbon Capture Storage (**CCS**), utilization of low NO_X burners, installation of desulphurization facilities, etc. These activities have especially large importance in case of older Large Combustion Power (**LCP**) plants, in particularly for those put into operation before 1 July 1987, and for which a specific and mostly case-by-case mitigation strategies must be developed.

Thermal Power Plant (**TPP**) Bitola is the largest **TPP** in the Republic of Macedonia which utilizes domestic lignite. Put into operation back in 1980s, all three units consisting TPP Bitola have already operated more than 200.000 hours each, therefore they are far beyond their normal life expectancy. There were two possible approaches for sustainable extension of their operational life: (1) replacement of all three units (*225 MW each*), with completely new and modern super critical power units and with total installed capacity of more than currently existing 675 MW, or (2) performing large-scale rehabilitation program of the existing units including boiler rehabilitation, lignite supply chain modernization, steam turbines, generators and control system modernization, desulphurization, etc.

Starting back in 2010, such large rehabilitation program on all three units has been initiated. Special attention during rehabilitation process was paid to environmental improvements and introduction of pollutant abatement systems providing that after rehabilitation, all three power units become fully compliant with the EU Directives for LCP Plants (*EU Directive 2001/80/EC*).

In this paper, the taken approach for selection of the best and the least-cost rehabilitation program is presented. Based on several constrain factors, four potential improvement scenarios were developed and investigated. The expected results, such as the unit's life prolongation, boiler efficiency increase and decrease of pollutant emissions compliant with the LCP Directive are also given, therefore, providing a unique approach towards sustainable operation of the existing cold-fired power plants beyond 2016.

Key words: Sustainable development, NO_X and SO_X emission reductions, Large Combustion Power (LCP) plants, Best Available Technologies (BAT), EU Directives.

1. INTRODUCTION

Thermal Power Plant (**TPP**) Bitola is the largest TPP in the Republic of Macedonia which utilizes domestic lignite [1]. The power plant is located in the southern part of the country near the city of Bitola and consists of three identical coal-fired power units originally of 210 MW capacities each, commissioned in 1982, 1984 and 1988, respectively. In 1994, all three units had capacity upgrade from the original 210 MW to 225 MW by means of increase of the steam flow. TPP Bitola utilizes

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locally-mined lignite and on average generates approximately 70% of the total domestically produced electricity. Hence, with its annual electricity production of around 4,600 GWh, TPP Bitola has a paramount importance for stability and security of the electricity market within the Republic of Macedonia. The average lignite consumption of Bitola TPP, depending on the lignite quality, is between 6,100,000 and 6,500,000 tons/year, and the resulting net electric efficiency is about 31-32%, which is rather low compared with the modern combustion type TPP which utilize the Best Available Technology (**BAT**) [4].

Put into operation back in 1980s, all three power units consisting TPP Bitola have already operated more than 200.000 hours each, therefore they are beyond their normal life expectancy, so that large-scale rehabilitation program was compulsory in the short term [2]. The main purpose of rehabilitation program was to identify the most appropriate rehabilitation activities for the power plant that will extend lifetime of the main equipment, improve energy efficiency and overall performance as well as reduce negative environmental impacts, taking into account the locally available lignite reserves and/or potential fuel supply schemes. The rehabilitation program should at least allow an overall life-extension of the plant of about 120,000 hours which corresponds to about 15 years of additional operation.

Being a large combustion plant fuelled with lignite, in fact, TPP Bitola releases significant amounts of pollutants into the atmosphere. At present, the plant is equipped only with three electrostatic precipitators (**ESPs**). Neither NO_X nor SO_X abatement systems are currently installed at Bitola TPP. As the lifetime of the existing units was planned to be "extended" for about 120,000 hours (*about 15 years of normal operation*), and the Republic of Macedonia is on its way to become an EU member in the next future, the respect of EU air emission limits becomes compulsory. The current concentrations of three major pollutants at the stack do not guarantee the respect of the current EU emission limits [2].

Having into account the existing BAT for LCP plants and some already performed modernization on similar TPP, three possible approaches for sustainable extension of their operational life of Bitola TPP were initially considered:

1) Performing large-scale rehabilitation program of the existing units including boiler rehabilitation, lignite supply chain modernization, modernization of steam turbines, generators and control system, desulphurization, etc.,
2) Replacement of all three units (*225 MW each*), with completely new and modern super-critical power units, fully compliant with the BAT for LCP plants, or
3) Mixed approach, based on rehabilitation of some of the existing units and adding some new and modern super-critical power units.

In this paper, the rationale behind the selection of the best approach for sustainable extension of operation life under existing EU Directives regarding for Large Combustion Power plants (*EU LCP Directive 2001/80/EC*) [3], is discussed. Additionally, the comparison between approaches is also presented, taking into account various constrained factors which provides a good example towards solution of similar problems for older TPP plants (*before 1st of July 1987*), in accordance with the valid EU Directives [3].

2. CONSTRAIN FACTORS AND ALTERNATIVES

As mentioned above, three possible solution of the following problem is investigated:

How to provide sustainable extension of the operational life of TPP Bitola with least-cost investments adhere to the EU Environmental Directives for the expected period of locally-mined lignite?

Obviously during evaluation of the best approach towards problem solution, several constrain factors had to be investigated:

1) The security of electricity production, not only after rehabilitation, but also during the

process of rehabilitation/replacement of existing units with new modern units,

2) The estimated life expectance of the local lignite mines, i.e. to estimate the amount of available and economically feasible quantities and qualities of lignite that could be extracted from the local mines and utilized for electricity production at TPP Bitola,
3) The amount of total investment necessary for realization of whole project, either rehabilitation of the existing units, or decommissioning of them and replacement with new units,
4) The achievable environmental improvements with large-scale rehabilitation program, and to compare these achievable values with prescribed approved values for each pollutant by the respective EU Directives for such power plants.

The above four critical issues had to be taken into account during the investigation of the best applicable solution for sustainable extension of operation life of Bitola TPP.

2.1. Security of Electricity Supply

Security of electricity supply during rehabilitation program execution is one of the most critical issues which had been taken into account. It was already mentioned that Bitola TPP is crucial power plant in the Republic of Macedonia for domestic electricity production which accounts for more than 70% of total electricity production within the country. The annual electricity production of TPP Bitola for the period before initiating the study (2005 – 2008) is given in Fig. 1, [2], [5]. Being out of operation for long period of time becomes a major economic, social and even a political problem in the country. Consequently, the only acceptable solution was to aim for periodically scheduled rehabilitation/replacement program that would provide a minimum negative impact on the overall energy situation in the country.

Having into consideration that design, procurement, erection and commissioning (**DPEC**) of a new power plant with installed capacity of several hundred MWs (*enough to replace the existing ones*) is a serious, complex and time-consuming task that would last at least several years, the full replacement of all three units with one, two, or even three new ones is very unlikely solution of the problem. Partial rehabilitation of some of the younger units and decommissioning and replacement with new one of other older units might be applicable in this case.

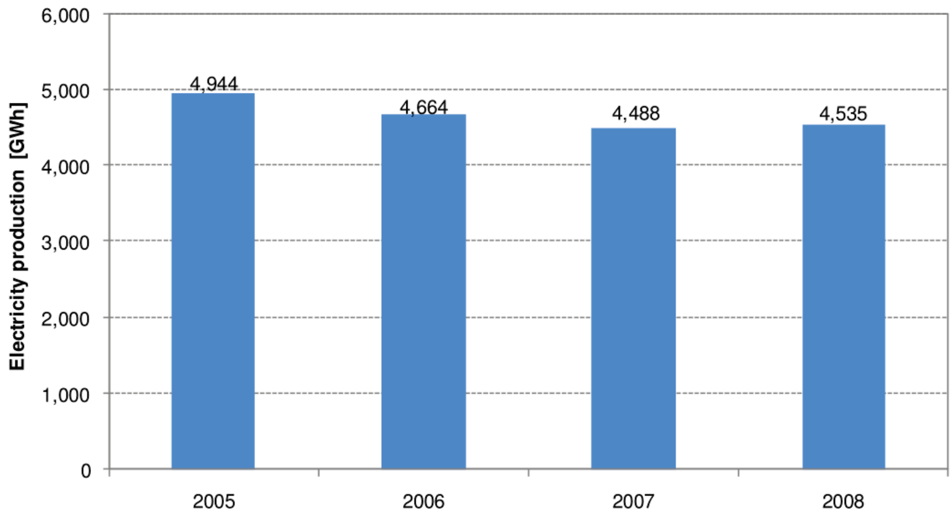

Fig. 1: *Total annual production of electricity at Bitola TPP from 2005 to 2008.*

2.2. Life Expectance of Local Lignite Mines

At present, TPP Bitola uses the locally excavated low-calorie lignite. There are two existing lignite mines in the vicinity of TPP Bitola, one is the older mine Suvodol with estimated amount of remaining lignite of about 20 million tonnes, and the newly opened lignite mine Brod-Gneotino with estimated amount of about 30 million tonnes. In addition to these two, there are activities for opening the third one, the so-called Lower Lignite Layers (**LLL**) below the existing surface mine Suvodol which according the performed studies could provide additional 50 million tonnes of lignite. With suitable combination and homogenization technology, these three lignite sources in total could provide approximately 100 tonnes of lignite. This could enable stable electricity production in the coming 15-16 years, taking into account that annual lignite consumption of TPP Bitola is between 6.1 and 6.5 million tonnes of lignite [6].

If one follows this reasoning, it is obvious that construction of a new thermal unit in TPP Bitola could not be fully justified since the operational life of these new units is between 25 and 30 years, a period for which local lignite mines cannot secure stable lignite supply. Further investigations might give some optimistic figures if one takes into account that the new units could have larger net efficiency (*app. 36-38%*) than the existing ones (*31-32%*). This 5% net efficiency increase could provide lignite savings of the same percent per year (*app. 320,000 tonnes/year*), or prolongation of operational life in total for the investigated 15 years for additional 4-5 years, that might be valuable only in case that the investment in the new units would be economically justified over the investment made in the rehabilitation of the existing units.

2.3. The Amount of the Investments

The amount of the investments and the possibilities to obtain these investment funds under most favourable financial conditions is a crucial issue, too. TPP are not favourable investments projects for the major international and domestic financial institutions (*EBRD, IBRD, KfW, EIB, etc*). Providing loans for coal-fired TPP is very challenging and highly unsecured task, due to their unfavourable environmental footprint – large emissions of CO_2, NO_X, SO_X, dust particles, etc.

It is more likely to obtain suitable loans for modernization, rehabilitation and environmental improvements of the older TPP units, than for construction of a new, even modern TPPs with BAT. Additionally, all new units come with BAT such as **CCS** (*Carbon Capture Storage*), low NO_X burners, desulphurization units, electrostatic precipitators, etc. The additional increase of the investments on one side, and in parallel, decrease of the unit's efficiency due to increasing the electricity self-consumption of the plants, on the other side, very often is not the best solution.

Finally, the financial capability and the available margin for taking new loans by the Macedonian Power Plants (**ELEM**) and the Macedonian Government as the owner of ELEM and TPP Bitola also had to be considered, with respect to the large amount of investment money, the ELEM's financial condition and the availability for further borrowings by the company, even with Sovereign Guarantee and under most favourable financial conditions.

2.4. Environmental constrains

TPP Bitola is one of the largest concentrated pollutants in the Republic of Macedonia regarding the emissions values of the Green-house Gasses (**GHG**), in particularly, NO_X, SO_X and dust particles. The current emission rates for all three pollutants are several times above the admissible rates by the LCP EU Directive [3] and the admissible rates of new and modern large combustion power plants burning lignite and utilizing the **BAT**. The average values for three most significant pollutants, NO_X, SO_X and dust particles are given in Table 1, while the annual emission rates for the Bitola TPP are given in Figs. 2, 3 and 4.

Table 1: *Average pollutant concentrations released by TPP Bitola per year.*

Pollutant	Average Concentration (mg/Nm^3)	LCP Directive, existing plants @6% O_2	After 2016 – New proposed Directive, existing plants @6% O_2
NO_X	550	500	200
SO_X	2,700	400	200
Dust particles	300	50	30

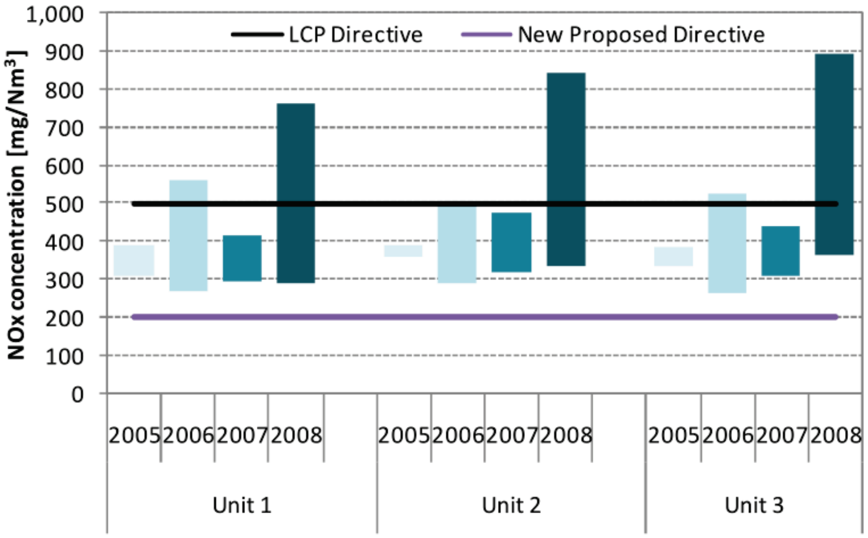

***Fig. 2:** Trend of NO_X concentration at the stack at TPP in Bitola from 2005 to 2008.*

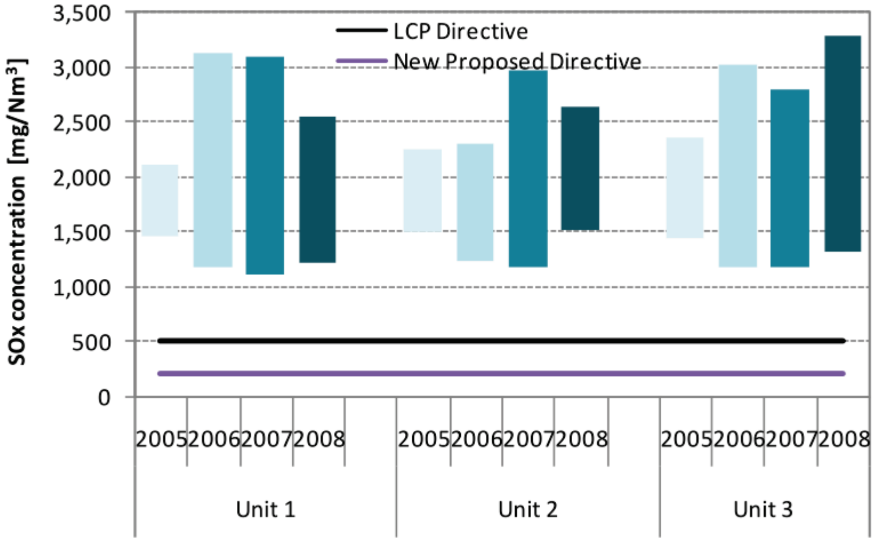

***Fig. 3:** Trend of SO_X concentration at the stack at TPP in Bitola from 2005 to 2008.*

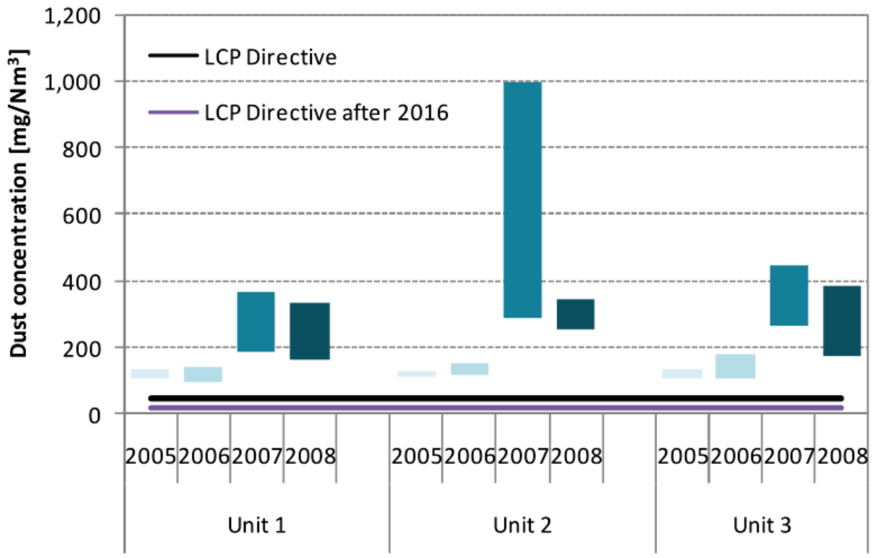

***Fig. 4:** Trend of dust concentration at the stack at TPP in Bitola from 2005 to 2008.*

It is obvious from the presented data that the current emissions rates have to be drastically decreased in order to adhere with the EU Emissions LCP Directive [3].

For example, the average amount of NO_X emissions is little above Directive. However, since after 2016 the admissible amount would drop down to only 200 mg/Nm^3, that means that the average value has to be reduced by one half. The situation with emissions of SO_X is even worst. From average value of 2,700 mg/Nm^3, it is necessary to decrease the emission rates first to 400 mg/Nm^3 (*almost 7 times*), and beyond 2016 further down to 200 mg/Nm^3, or almost 14 times. Similar results are observed in case of dust particles, where in order to adhere to LCP Directive before 2016 the amount of dust emissions must be reduced 6 times, from current 300 mg/Nm^3 to admissible 50 mg/Nm^3. Beyond 2016, the situation is even tougher, and the reduction rate has to be even 10 times, from existing 300 mg/Nm^3 down to only 30 mg/Nm^3. All these requirements are very difficult and very expensive to achieve. However, the EU Directives are must for anyone who would like to continue with electricity generation using coal as a fuel and in the same time to pursuit accession with other EU, and does electricity trade within EU borders.

With respect to all said above, Table 2 shows the potential paths that could be taken in order to satisfy the sustainable exploration of the power plants under given constrains.

Table 2: *Analysis of potential benefits of various approaches for sustainable operation of TPP Bitola.*

Constrains	Large-scale rehabilitation of the existing power plants	Design, procurement, erection and commissioning of new power plants	Mixed approach: rehabilitation + construction of new power plants
Energy security	+++	+	++
Lignite deposits	+++	+	++
Investments	++	+	++
Environment	+	+++	++

One can conclude that the most benefits should be expected from the approach based on the large-scale rehabilitation program of the existing power plants, followed by the mixed approach. The decommissioning of the existing power plants and their replacement with new and modern **BAT** power plants is the least attractive solution. Consequently, the following four applicable scenarios for long-term sustainable operation were investigated:

- **Scenario #1** – Rehabilitation of the all three existing units;
- **Scenario #2** – Rehabilitation of the two existing units, and building one new 300 MW_{el} unit;
- **Scenario #3** – Rehabilitation of one existing unit, and building one new 500 MW_{el} unit, and
- **Scenario #4** – Building of two new units, one 500 MW_{el} unit, and one 300 MW_{el} unit.

3. SELECTION OF BEST EVALUATED SCENARIO

The selection process for the best scenario need one more parameter to be taken into account during the investigation – the cost of electricity produced by each of four suitable scenarios after rehabilitation/replacement process is finished. Electricity prices in the Republic of Macedonia are quite low, mostly due to the fact that most of the generated electricity comes from power plants (*most significant being TPP Bitola*) burning local quite cheap lignite. If the generation electricity prices change drastically by imposing any of the above scenarios, this would have significant impact on the majority of the industry and households. This would have a large financial impact on the economic development of the country and negative social reflections on the living standards of its citizens. The expected electricity prices as a result of this major rehabilitation/replacement have large influence on the selection of the best evaluated scenario.

The performed feasibility study [5] for each of the above proposed scenarios, showed that the most economically feasible scenario, resulting with full achievement of all predefined requirements (*constrains, EU Directives, electricity prices, etc.*), is the **Scenario #1 – Rehabilitation of the all three existing units.** The levelled prices for electricity generated after implementation of each of four potential scenarios are given in Fig. 5.

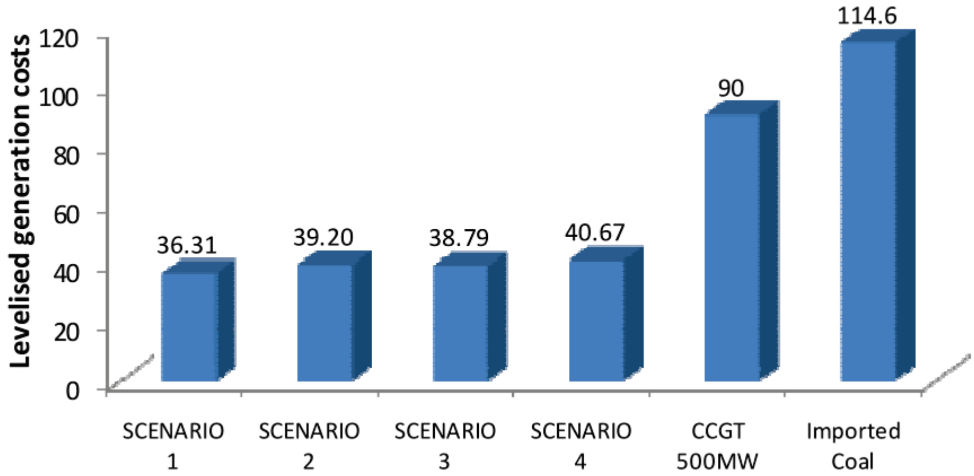

Fig. 5: *Comparison of the levelled generation costs of the various options considered.*

To further investigate feasibility of each of proposed scenarios, the expected electricity prices from two additional scenarios are also given in Fig. 5:

1. The replacement of the existing coal-fired power plants with new 500 MW combined-circle gas-fired turbines (CCGT), and
2. The rehabilitation of the existing plants with new primary equipment suitable to work on imported high-calorie coal.

As seen, the lowest generation prices of 36.31 €/MWh should be expected by implementing the large-scale rehabilitation program on primary and secondary equipment of all three existing power plants.

The best evaluated Scenario #1 comprises of [2]:

1) Rehabilitation and modernization of the steam turbines and steam paths,
2) Rehabilitation and modernization of the generators and excitation systems,
3) Implementation of new power control and automation system,
4) Replacement of old motors used for pumps and fans,
5) Rehabilitation and modernization of coal supply systems and coal mills,
6) Full rehabilitation of boilers using new low NO_X burners, pipe system and control system and automation,
7) Implementation of new pollutant abatement systems for all three units, etc.

Due to large investment cost in total and taking into account the security of electricity supply, JSC Macedonian Power Plants (ELEM) took decision to perform all above mentioned activities divided into three separate phases:

- **<u>Phase #1:</u>** Full rehabilitation of the steam turbines, generators and power control & automations system. This phase started in 2010 for Unit #1, 2011 for Unit #2, and in 2012 for Unit #3.
- **<u>Phase #2:</u>** Boiler rehabilitation, including implementation of primary measures for lowering NO_X emissions using new low-NO_X burners, modernization of pipe system and control & automation system. This phase stared in 2012 with Unit #3, continued in 2013 with Unit #1, and in 2014 it is expected to finish with Unit #2.

- **Phase #3:** Implementation of new pollutant abatement systems, especially, erection of new wet-spray desulfurization system and new electric precipitations (*bag house filters*). This phase is still under preparation (*Feasibility study is finished*) and is scheduled to take place after 2015.

The expected outcome regarding the environmental improvements after implementation of the whole pollutant abatement system, including decreasing emissions of NO_X with realization of Phase #2, is given in Table 3.

Table 3: *Pollutant abatement systems – expected results and cost.*

Pollutant	Abatement Techniques[§]	Concentration @ boiler [mg/Nm 3]	Abatement efficiency %	Concentration @ stack [mg/Nm 3]	Estimated Investment cost [€]
NO_X	Primary measures only	550	27%	400	5,000,000
	Primary measures and High Dust SCR	550	70%	200	60,000,000
SO_X	Spray Dryer - FGD	2,700	88%	400	90,000,000
	Limestone gypsum FGD system	2,700	94%	200	110,000,000
Dust	Bag House Filter	27,200	99,8%	50	45,000,000
	Bag House Filter	27,200	99,9%	20	45,000,000

According the presented data, the total cost only for full implementation of pollutant abatement system is estimated between 150,000,000€ – 195,000,000€ for full compliance with the EU LCP Directive, up to 235,000,000€ for compliance with the EU Directives beyond 2016. It is obvious that the investment amount is considerably high, especially having in mind that with this investment no additional electricity could be generated. On contrary, the amount of generated electricity could be lower due to increase of self-consumption of the rehabilitated plant by few percents.

Before presenting the conclusion remarks of the investigation of the benefits of the proposed rehabilitation scenario that ensures long-term sustainable operation of the power plants in TPP Bitola based on local lignite, a comparison of several crucial parameters for all four suggested scenarios are presented in Table 4.

Table 4: *Comparison between four potential scenarios.*

Parameter	UoM	Scenario #1		Scenario #2		Scenario #3		Scenario #4	
		MPC[**]	FPC[††]	MPC	FPC	MPC	FPC	MPC	FPC
Power output	*MW*	711		474 (old) +300 (new)		237 (old) +500 (new)		300 (new)+500 (new)	
Production	*GWh/y*	**4,834**		**5,263**		**5,011**		**5,440**	
Efficiency	*%*	28.5		28.5 (old) ; 41.3 (new)		28.5 (old) ; 41.5 (new)		41.3 – 41.5	
LHV (coal)	*MJ/ton*	7,500		7,500		7,500		7,500	
Life time	*Years*	15		15 (old) ; 30 (new)		15 (old) ; 30 (new)		30	
Rehabilitation cost per unit	*M€*	3 x 80		2 x 80 (old) + 450 (new)		1 x 80 (old) + 650 (new)		450 – 650	
Total CAPEX	*M€*	**240**		**610**		**730**		**1,100**	
Lignite cost	*€/ton*	15	20	15	20	15	20	15	20
Electricity price	*€/MWh*	40	60	40	60	40	60	40	60
IRR	*%*	**17.39**	**21.02**	**8.81**	**20.82**	**8.95**	**18.89**	**7.60**	**15.35**
Pay Back Time	*Years*	**8**	**6**	**22**	**7**	**22**	**7**	**31**	**10**
Generation cost	*€/MWh*	**36.31**	**44.73**	**39.20**	**46.43**	**38.79**	**45.28**	**40.67**	**46.48**

4. REDUCTION OF CO_2 EMISSIONS

The reduction of CO_2 emissions was not discussed by now. Naturally, burning coal, especially low-calorie lignite is always followed with large CO_2 emissions, which further aggravates the environmental footprint of coal-fired power plants. Bitola TPP has the similar problems and it is

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[§] Techniques implemented to achieve compliance with LCP Directive emission target (*pink*), and compliance with the Directives beyond year 2016 (*green*).

[**] **MPC** stands for Most Possible Case – coal prices set @15€/ton, and selling electricity prices set @40€/MWh.

[††] **FPC** stands for Future Possible Case – coal prices set @20€/ton, and selling electricity prices set @60€/MWh.

concerned as one of the largest solely CO_2 emission pollutant. This situation would not change significantly with the rehabilitation program because, after the rehabilitation, the amount of burned coal would be only modestly reduced as direct result of small increase of the plant's efficiency. However, if instead of rehabilitation, one decides to select one of other three scenarios which include new units, than as a result of larger increase of efficiency of new BAT TPP with respect to the existing ones, the quantity of burnt coal would decrease, consequently, this would lead to decrease of CO_2 emissions. Beside the environmental benefits, these solutions also might provide significant financial benefits if the reduced CO_2 emissions are transferred into CO_2 Certified Emission Reduction (**CER**) credits, and later sold on the carbon reduction market. Depending on the CERs price, the amount of additional revenues might support some intensive investment schemes.

Figure 6, shows the expected amount of CO_2 emissions in respect to all four scenarios. As one can notice, the amount of reductions achieved annually with scenario #4 in respect to best evaluated scenario #1 is 1,359,480 tonnes. If the market price of one ton reduced carbon emission is 20 €/ton, the additional revenues could amount 27,189,600€/year, which is definitely worth of consideration. However, the carbon market in the World and especially in Europe is still unstable and the prices are volatile. Therefore, these revenues are not taken into consideration at this stage of analysis.

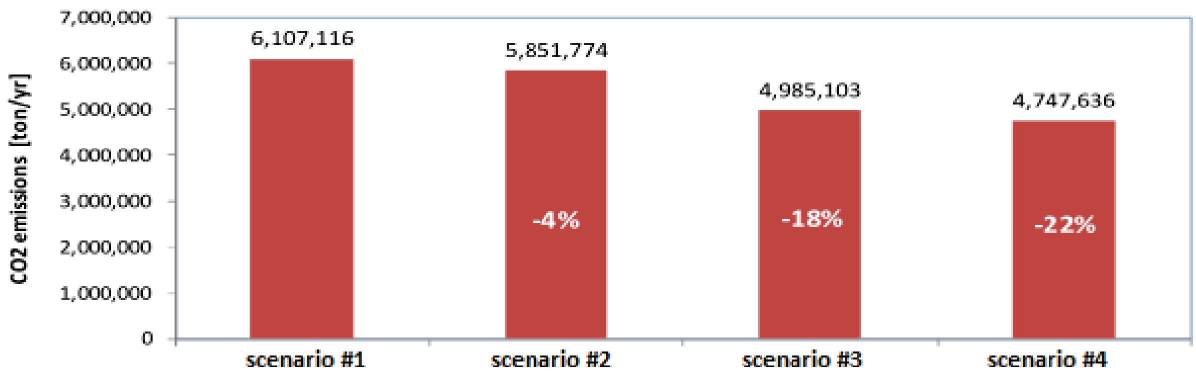

Fig. 6: *CO2 emission reduction for various scenarios.*

5. CONCLUSIONS

Burning coals is, and it would be a widely utilized technique for electricity production in the near future. Many world economies directly or indirectly depend on exploitation and utilization of coal, either on low-calorie lignite, brown coal or anthracite. Many power utilities still strongly depend on coals, locally excavated or imported, such as Germany, Poland, Ukraine, Russia, China, India, or even closer to us, Bosnia & Herzegovina, Serbia, Macedonia, Bulgaria, Greece, etc. Even more important is the fact that majority of the power plants which burn coals are older and most of them did not fully comply with the newest and most strict environmental policies and directives imposed by EU. Therefore, solution of these problems cannot be general, but rather case-by-case approach should be taken.

In this paper, the authors presented one possible approach how to deal with the problem of wearied primary equipment which is at the end of its operational lifetime, and in parallel to solve the critical environmental problems of pollutant emissions above the prescribed values by EU LCP Directive.

A subject of the presented analysis was the TPP Bitola, the largest coal-burning power plant in the Republic of Macedonia. The main project target was to enable sustainable operation of this power plant as long as the local lignite mines could provide annually needed coal quantities, or approximately enough lignite quantities for the next 15 – 16 years. Additionally, as a secondary, but by no means lesser need, increase of the power efficiency, O&M cost decrease and improving the environmental parameters to be compliant with the existing and planned EU LCP Directive were also set as project targets.

During analysis, a set of constrains were also introduced such as security of electricity supply, amount of available lignite in the future, total investment cost, etc., in order to obtain the optimal project scenario among four most likely ones. Potential scenarios ranged between large-scale rehabilitation projects of all three existing units, and decommissioning of the existing units and their replacement with one or two new BAT coal-fired power plants.

As a result of the extensive analysis, scenario #1 comprising large-scale rehabilitation program of the primary (*turbine, generator, boiler, control system, etc.*) and some parts of the secondary equipment (*lignite mills and feeding system, water and air feeding systems, etc.*), were selected as best evaluated scenario. This scenario not only fulfils the main target – prolongation of operational life of the units, but it also provides all other expected benefits in respect to efficiency increase and pollutions abatement system implementation with least cost investment program. It provides at least 15 years of sustainable operation life of all three units with at least 17.39% of IRR and Pay Back Time (**PBT**) of about 6 years, and with minimum generation electricity prices as low as 36.31 €/MWh. If reduction of CO_2 is additionally considered and accumulated CERs are sold on the future European carbon market, the feasibility of the rehabilitation schemes should be further investigated and justified in practice.

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BIOGRAPHIES

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