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Correlation between eco-efficiency measures and resource and impact decoupling for thermal power plants in Serbia

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A B S T R A C T

Electricity generation using carbon-based fuels is responsible for a large fraction of carbon dioxide emissions worldwide. In Serbia, 70% of the electricity is produced from coal-fired power plants. The aim of this investigation was to identify the retrofitting opportunities to reduce the carbon intensity of power generation. Resource Efficient and Cleaner Production assessment was performed in a coal thermal power plant of the public company “Thermal Power Plants Nikola Tesla”, which operates within the Electric Power Industry of Serbia. Assessment of the thermal power plant operation was supported by experimentally measured data (fresh water pressures and temperatures, steam temperatures and pressures, condensing pressure, water flowrate, make-up water flowrate, steam flowrate, coal composition, emissions, etc), emission factor determinations and by using data obtained during unit balancing and simulation of the system's performance. The data collected and analyzed during power plant operation were used for the development of a new general approach with comprehensive analysis of the system, using the following plant eco-efficiency indicators: energy consumption, climate change, acidification, and waste generation. Indicators were used to present decoupling after implementation of the described measures. The analysis of two units showed that the nominal power could be increased by 60 MWe, with an increase of the unit gross efficiency of 0.4%, and a reduction of coal, water and electricity consumption. The implementation of RECP measures in this study enabled analysis of the overall performance of the system as evidenced by the eco-efficiency indicators: energy consumption (decreased by 3%), CO_2 emission (decreased by 3%), and SO_2 emission (decreased by 39%).

Consequently, it may be concluded that the proposed RECP approach, tested on thermal power plants, and presented as eco-efficiency indicators show that the described methodology may be successfully implemented in the energy sector and for the improvement in power plants.

1. Introduction

Many papers, books and toolkits about resource efficient and cleaner production (RECP) indicate the significance and need for research in this area (Fresner and Yacooub, 2006; Henriksson and Söderholm, 2009; Mattsson et al., 2010). Some of the studies focused on the better management of chemicals (Lozano et al., 2013), a number of studies analyzed the potential for water reduction (Willers et al., 2014), or the application of RECP methods in general (Lozano, 2012; Price et al., 2002). However, in the case of industry, energy consumption has still remained the major topic. A trend of increasing energy use, especially in developing countries, and projections according to which the world's energy consumption will increase by 33% from 2010 to 2030 (Abdelaziz et al., 2011), necessitated further research and demonstration of the implemented measures (Dobes, 2013; Fresner et al., 2010; Laforest et al., 2013) in both directions: increasing the efficiency of energy use and reducing greenhouse gas emissions (GHG).

A literature search indicated that most studies on energy efficiency have dealt with manufacturing processes, especially with

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the energy efficiency potentials of energy-intensive industries (e.g., chemical and petrochemical, iron and steel, pulp and paper) (Abbaszadeh and Hassim, 2014; Posch et al., 2015; Saygin et al., 2011). Some studies, however, have shown (Tzolakis et al., 2012; Wang et al., 2013) that a great potential for the reduction of energy consumption actually exists in the energy manufacturers themselves, in plants for the production of electricity, especially thermal power plants.

Most plants for the production of electricity in Serbia are owned by the Public Enterprise – Electric Power Industry of Serbia (EPS), the total capacity of which for the production of electricity is 7124 MW. EPS encompasses six coal thermal power plants (55% of the total installed capacity), eleven hydro power plants (40%) and gas burning combined heat and power plants (5%) (EPS, 2014). In 2013, 37,433 GWh of electricity were produced in EPS power plants, 70% of which in coal thermal power plants (MME, 2014).

In terms of energy, Serbia is among the 20 most energy intensive countries in the world regarding energy use per GDP. Moreover, Serbia emits relatively large amounts of GHG emissions deriving from the combustion process, measured per unit of GDP by purchasing power parity (MESP, 2010; SuDES, 2012). Certainly, electricity production represents one of the most significant influences on the environment regarding the amount and quality of coal used as the raw material in thermal power plants (Jovančić et al., 2011). In addition to environmental issues, there is another issue related to the efficiency of old thermal power plants. Such old plants have an average net plant efficiency of only slightly more than 30%, due to equipment design, but also due to leakage and fouling and old boilers that are not optimized to use different type of fuels (e.g. biomass) (Abb, 2009).

Since 2000, EPS, the Serbian Government and international financial institutions (primarily from the European Union) have jointly made considerable efforts to improve environmental protection. Most of the funds have been invested in the modernization of existing plants, which has achieved a total savings of coal in the amount of 4.2 million tons a year and have, at the same time, increased the production of electricity to the power of a new block of 400 MW and the energy efficiency to 12% (EPS, 2009). Projects, such as the construction of a wastewater treatment plant at one of the thermal power plants and the installation of desulphurization units, have been initiated to reduce emissions and harmonize them with the requirements of the Industrial Emission Directive (EPS, 2011; LCP BREF, 2006). The implementation and operation of such units will increase auxiliary power in the range of 1–3% (Abb, 2009).

Cleaner production initiatives in EPS started in 2011 by involving four coal thermal power plants of the public company "Thermal Power Plants Nikola Tesla" (TENT), which operates within the Electric Power Industry of Serbia. The RECP method (UNEP and UNIDO, 2010) was developed and adopted to the conditions of the thermal power plants and later applied in six other plants of the EPS Company. This approach and the involvement of all the power plants have enabled an intensive exchange of data and experience between the team members of the plants. Both the economic and environmental benefits of the applied methods are presented in this paper, emphasizing the methods of examining the present condition of the plant, as well as the analysis of its operation and the possibilities of increasing its efficiency. The environmental impact of the power industry, especially of coal-fired thermal power plants on air emissions and the environmental indicators related to climate change and acidification were analyzed. Conversion factors were calculated based on the laboratory analysis of the coal used in Serbian power plants. Special eco-efficiency indicators were used to present decoupling after implementation of the described measures.

2. Implementation of resource efficient and cleaner production at the Thermal Power Plants Nikola Tesla

The company "Thermal Power Plants Nikola Tesla" is the largest manufacturer of electricity in Southeast Europe. It has 14 units, with an overall installed power of 3286 MW, which is one third of the installed capacities of the Electric Power Industry of Serbia, and it annually accounts for more than 50% of the electricity produced in Serbia.

The company TENT consists of 5 organizational parts. They are: TENT A in Obrenovac (6 units with a total power of 1650 MW), TENT B in Obrenovac (two units, 620 MW each), the Thermal Power Plant "Kolubara" in Veliki Crljeni (5 units with a total power of 271 MW), the Thermal Power Plant "Morava" in Svilajnac (one unit of 125 MW) and the Rail Transport, which annually transports around 28 million tons of lignite from the open pit mines of "Kolubara".

The research carried out at the Thermal Power Plants was focused on finding solutions for the modernization of existing units, by increasing their capacities and reducing specific energy consumption, while reducing emissions to air, water and the amount of generated waste. The application of RECP was based on material and energy balance analysis, best available techniques assessment, the modeling, simulation and optimization of existing processes and equipment, the selection of appropriate options and the evaluation of these options in terms of environmental impact and regarding the technical and economic aspects.

2.1. Heat and material balance

Data for the mass balance were collected for a period of three years on the electricity produced (MWh), the amounts of consumed coal (in tons, as well as its calorific value in kJ and MWh) and heavy oil, on the consumption of chemicals, oil and lubricants, as well as the amounts of produced waste and emissions. The electricity on the generator, self-consumption and the electricity taken from the grid were taken into consideration for the energy balance. The water balance for different types of water – demineralized water, decarbonized water, cooling and sanitary water, was prepared separately.

Based on the analysis of the collected data, performance indicators (UNIDO and UNEP, 2010) were established that would be the most significant for all the thermal power plants. The same indicators, such as (kg of coal)/(kWh produced), (kg of ash generated)/kWh produced), (kJ of coal)/(kWh produced), % of own electricity consumption, (m^3 of demineralized water)/(GWh produced), kg HCl/m^3 of demineralized water and kg of NaOH/m^3 of demineralized water, were calculated for the TENT power plants (Table 1) and evaluated. The significance of the indicators in Table 1 is the possibility to compare data between the units within one plant, and more importantly, among the thermal power plants for the whole Electric Power Company.

2.2. Emission factors

The quality of lignite used in the thermal power plants was analyzed for the same considered period in order to calculate emission factors related to air pollution. The following lignite properties were determined: bulk density, moisture content, ash, volatile matter in the analysis sample, fixed carbon, gross calorific value (by the bomb calorimetric method and calculation of the net calorific value), total sulfur (Eschka method). The analyzed samples were collected for different units of the power plants in order to ensure the simulation of a wide spectrum of the expected qualities of coals conveyed to the thermal power plants. The net calorific value ranged from 5500 kJ/kg to 9000 kJ/kg and had a moisture content between

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