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# Modelling and optimization of combined cycle power plant based on exergoeconomic and environmental analyses

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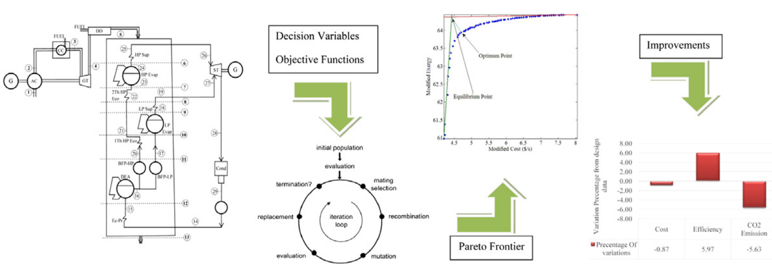
## GRAPHICAL ABSTRACT

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## ABSTRACT

This research paper presents a study on a comprehensive thermodynamic modelling of a combined cycle power plant (CCPP). The effects of economic strategies and design parameters on the plant optimization are also studied. Exergoeconomic analysis is conducted in order to determine the cost of electricity and cost of exergy destruction. In addition, a comprehensive optimization study is performed to determine the optimal design parameters of the power plant. Next, the effects of economic parameters variations on the sustainability, carbon dioxide emission and fuel consumption of the plant are investigated and are presented for a typical combined cycle power plant. Therefore, the changes in economic parameters caused the balance between cash flows and fix costs of the plant changes at optimum point. Moreover, economic strategies greatly limited the maximum reasonable carbon emission and fuel consumption reduction. The results showed that by using the optimum values, the exergy efficiency increases for about 6%, while $CO_2$ emission decreases by 5.63%. However, the variation in the cost was less than 1% due to the fact that a cost constraint was implemented. In addition, the sensitivity analysis for the optimization study was curtailed to be carried out; therefore, the optimization process and results to two important parameters are presented and discussed.



## 1. Introduction

Sustainable energy production requires careful steps of efficiency improvement (resource management) and provides environmental friendly energies. Thermal power plants are the most common in many power production sites around the world. These industries are forced to revise their technologies, use more green options and high efficient cycles. Therefore, multi-objective optimization of a combined cycle power plant in terms of economy, efficiency and environmental aspects is one step further to solve this issue. Power plant is a key item in producing electricity. Among different kinds of power plants, CCPPs have gained a lot of attentions because they are attractive in power generation field due to their higher thermal efficiency than individual steam or gas turbine power plants, and cause less environmental impact [1–4]. To optimize the efficiency, cost effectiveness and environmental impact of such plants, it is important to determine the locations, types and

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magnitudes of true inefficiencies (irreversibilities) beforehand. Exergy analysis is a useful tool for such analyses, and to permit quantification of the thermodynamic inefficiencies of the process [4–6]. Exergy is a measure of the utility or value or quality of energy form. Technically, exergy means the use of thermodynamics principles for the maximum amount of work that can be generated by a system or a flow of matter or energy as it comes to equilibrium with environment. During the past several decades, many researchers have carried out exergy analyses of power plants. Rosen et al. [7] evaluated the role of exergy for increasing the efficiency and sustainability, while reducing environmental impact. The paper discussed about the capability of exergy for efficiency improvement. Furthermore, the environmental implications of exergy were proposed, which were related to greenhouse gases and environmental pollutants and impacts. The paper also discussed some of the advantages of exergy with the goals of demonstrating how exergy can assist to improve understanding of green energy, and thus help increase their utilization. Ameri et al. [1] also performed the exergy analysis of the supplementary firing in an HRSG in a combined cycle power plant in the north of Iran. The main goal of that research study was to evaluate the irreversibility of each part of a combined cycle power plant through the exergy analysis. Moreover, they calculated the exergy efficiency of each component for two different cases. The first one was when the supplementary fire was used while the second pace was without supplementary fire. Their results also showed that the most exergy destruction occurred in the combustion chamber, which was mainly due to its high irreversibility, and the second major exergy destruction took place in HRSGs. In another research, Cihan et al. [8] carried out the energy and exergy analyses for a combined cycle located in Turkey. They made a conclusion on the energy and exergy efficiency and exergy destruction of each part of the power plant. They also compared the overall energy and exergy efficiencies and exergy fluxes at the inlet and the exit of the components at the power plant. The results showed that the main sources of irreversibilities were gas turbines, combustion chambers and heat recovery steam generators (HRSG) which had more than 85% of the overall exergy losses. Economic issue is important in the evaluation of energy technologies, energy conversion devices and costs of energy system. Some researchers [9–12] have suggested some methods which show costs are better shared among outputs based on exergy. Therefore, most sustainable energy methods have been developed on performing economic analyses based on exergy, which are called as second law costing, or thermoeconomics and exergoeconomics [10–14]. Many such studies have been reported, especially for power generation. Rosen and Dincer [9] performed an exergoeconomic analysis of power plants and applied it on a coal fired electricity generating station. They concluded that one of the significant parameter in evaluating the plant performance is the ratio of thermodynamic loss rate to the capital cost, which may be a successful tradeoff in the design of the plant. They also determined that exergy analysis and exergoeconomic analysis are not enough to determine the optimal design parameters in energy systems. Therefore, optimization must be applied to find the best design parameters in these systems. Ghaebi et al. [15] proposed the energy, exergy and thermoeconomic analysis of a combined cooling, heating and power (CCHP) system using a gas turbine as a prime mover. Therefore, the first and second laws of thermodynamics were combined with thermoeconomic approaches. They also conducted the exergy analysis to calculate the exergy destruction rate in each component, the effects of below items on the fuel consumption, the first and second laws efficiencies, and values of cooling, heating and net power output. Ahmadi et al. [16] conducted the modelling and exergoeconomic optimization of a gas turbine with absorption chiller using evolutionary algorithm. Moreover, to find the best design parameters for this case, they applied a multi-objective optimization. For the optimization, two objective functions (fuel cost, purchase cost of each tools and the cost of exergy destruction) were proposed. The results showed that by increasing the unit cost of fuel, it led to the selection of design values in a way that the objective function was decreased. One of the most important concerns for human is to reduce environmental impact of energy system and make use of sustainable energy technologies to mitigate global warming. Reduction of $CO_2$ emission can increase efficiency. For instance, the United Nations [17] stated that the effective atmosphere protection strategies should address the energy sector by increasing efficiency and shifting to environmental. Some exergy methods have indeed tried to reduce exergy losses and increase exergy efficiency, but there are some other ways that exergy can assist to understand and reduce environmental impact. Rosen and Dincer [18] introduced and discussed the relationships between exergy and environmental impact. On the other hand, there are some papers in the literature which were carried out by considering the environmental aspect of thermal systems, as the following: Barzegaravval et al. [19] studied the thermoeconomic environmental multi-objective optimization of a gas turbine power plant using evolutionary algorithm. They considered three different objective functions and used multi-objective optimization in order to optimize the system for better performance assessment. The results from optimization showed that the overall exergoeconomic factor of the system increased from 32.79 to 62.24% compared with the actual power plant. Ahmadi and Dincer [20] also investigated exergoenvironment analysis and optimization of a cogeneration plant system using multimodal genetic algorithm. They found that increasing air compressor isentropic efficiency resulted to the decrease in the compressor power consumption. Moreover, increasing the unit cost of fuel resulted to the decrease in the combustion chamber inlet temperature. To increase the net electrical power of the unit, more efficient equipment should be chosen. In another article, Gnanapragasam et al. [21] examined the effect of supplementary firing options on cycle performance and $CO_2$ emissions of an IGCC power generation system. The authors studied various kinds of HRSG from thermodynamic analysis viewpoint without thermal design and economic or optimization considerations. Ganjehkaviri et al. [22] conducted an exergoenvironmental optimization of heat recovery steam generators (HRSGs) in combined cycle power plant, through energy and exergy analysis. The result showed an increase in HRSG inlet gas temperature until 650 °C, leading to the increase of the thermal efficiency and exergy efficiency of the cycle, but later had less improvement and started to reduce. Also from the exergy analysis of each part of HRSG, it was shown that the HP-EV and 2nd HP-SH had the most exergy destruction. Besides that, the effects of HRSG inlet gas temperature on SI (sustainability index) and $CO_2$ emission were also considered.

In the present work, a computer program had been developed for energy, exergy, exergoeconomic and exergoenvironmental of a CCPP. Then, a multi-objective optimization of a CCPP was conducted. The effects of economic parameters variations on the sustainability, carbon dioxide emission and fuel consumption were also studied. Since the design variables of gas cycle and steam cycle were a function of economic parameters, the variation of these design parameters was considered. Therefore, in our multi-objective optimization, three deferent objective functions were considered, including the CCPP exergy efficiency, total cost rate of the system product and the $CO_2$ emission.

Therefore, in summary, the followings are the specific contribution of this paper in the subject matter area.

- To develop a comprehensive model for a CCPP with dual pressure HRSG.