題 目　Domestic Coal Supply Optimization Scenario towards Sustainable Development in Indonesia

(持続可能な開発に向けたインドネシア国内の石炭供給最適化シナリオ)

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Energy is one of vital part to achieve the Sustainable Development Goals (SDGs). Coal is considered as one of the most abundantly and the cheapest available energy source, particularly in the developing country. Indonesia is one of a country that still heavily rely on coal to fulfill its national primary energy demand, particularly for electricity generation which in majority is generated by coal-fired power plants (CFPPs). Coal holds major role as raw material to generate power, as well as key component in metal production. However, coal utilization is facing greater challenges in terms of economic, environmental, and social concerns.

Indonesia plays an important role in the global coal market. In 2018, Indonesia ranked as the 5th largest coal producer and the 2nd largest coal exporter in the world. However, only 21% of the production volume is utilized in the domestic market. In the future, Indonesia's coal production is expected to continue to increase due to the growth in coal demand for electricity generation. This research aims to predict the future of coal production in Indonesia to support economic growth considering less damage to the environment and more benefits to the social community, and examine its contribution to the national primary energy mix as a part of national energy policy.

System dynamics model is utilized, which simulates the future of coal supply and demand in relation to the availability of coal reserves, the interaction between coal and its substitutes, economic growth, and the price of commodities. Four scenarios are introduced to analyze the impact of coal utilization to the economy and environment, which are Business as Usual (BaU), Economic Growth Priority (EGP), Policy Regulation (PR), and Environmentally Oriented (EO) scenario. The results show that coal production in Indonesia will continue to increase in the future. The EO scenario will be the best alternative for future energy policy in Indonesia because of its ability to fulfill both economic growth and low carbon intensity target. Furthermore, the EO scenario also able to achieve the government target in primary energy mix in 2030 with 33.5% of coal, 19.4% of oil, 7.8% of gas, and 39.3% of renewable energy.

Indonesian coal is distributed in several islands, such as Sumatra, Kalimantan, Sulawesi, and Papua. Most of them are classified as low and medium rank coal, which is very suitable for coal-fired power plants. In the future, domestic coal demand will increase, driven by the government plans to increase the electricity generation capacity and primary energy demand. In the existing scheme, only a coal mining company whose coal quality is an exact match with the CFPP specification can be selected as a supplier, without considering a blending mechanism. This condition may have some issues for long-term supply, as the coal will be exhausted in time and tends to come at a high cost.

To improve the decision making for securing the long-term coal demand for electricity generation, optimization with coal blending should be considered. This research includes the

consideration of the coal quality parameters; the power plant's requirement criteria; the location of the coal blending facility; and ship types. In order to optimize coal utilization in Indonesia, it is necessary to consider economic, environmental, and social factors which in the existing condition only economic aspect that has been considered. Therefore, economic-environment-social model is constructed to solve the problem. A multi-objective optimization using mixed-integer linear programming, consisting of linear inequalities in binary and continuous variables as the constraints, is introduced to find the optimal solution, with cost, carbon dioxide (CO_2) emission, and social benefits as the objective functions. In this study, cost represents the economic aspect, CO_2 emission represents the environmental impact, while social aspect will be represented by the corporate social responsibility (CSR) programs as well as the human development index (HDI) in several province with high coal dependency. In most research on optimization, social aspects were analyzed by using the number of workers, which often neglects the fact that the same job can have different social benefits in different regions. The utilization of HDI which consider education, healthiness, and economic level of a region may give better understanding on social impact from coal mining industry to the society. Prioritization for underdeveloped and fast-growing region is considered in this study.

Several scenarios, which are the baseline condition, chartered ship, and environmental consciousness, are analyzed. The results obtained by using the epsilon-constraint method show the benefits of the proposed schemes and scenarios, which are able to secure long-term demand with a more flexible solution, and reduce the total cost and carbon dioxide emission, as well as increase the social benefits. Furthermore, considering the parameter setting and modeling, the optimization can be considered as applicable for solving similar problems related to the transportation selection and supply chain for similar commodities in the greater area. The results of the research perhaps can be utilized by the decision makers to improve the coal utilization towards the sustainable development.