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Reconciling strategy towards construction site selection-layout for coal-fired power plants

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HIGHLIGHTS

- A proper spatial analysis is vital to a sustainable energy system.
- A reconciling strategy is designed to conduct a suitable site selection-layout research.
- Three mechanisms are designed in the reconciling strategy.
- Problem complexities are handled by a bi-level modeling technique.
- The reconciling strategy is effective and can be used in other energy systems.

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ABSTRACT

There is an increasing debate on a new coal-fired power plant (CPP) construction over a demanding economic development and pressing environmental issues. A fundamental spatial analysis is required to identify potentially suitable sites, select a site and design a layout plan that are crucial for a sustainable energy development. The site selection and layout planning problems are mutually dependent. The different selection of the sites may lead to variations in the site layout plan, and vice versa. A proper site selection-layout planning solution is vital to the environmental, economic and social performances of a coal-fired thermal energy system. This study proposes a reconciling strategy to address the site selection and layout planning problems simultaneously. In specific, three types of conflicts in the site selection and layout planning processes are deliberately identified and quantified. To reconcile the conflicts, address practical constraints, and arrive at a "win-win" solution, three mechanisms are introduced and a bi-level multi-objective optimization model is established. Subsequently, a bi-level particle swarm optimization (BiPSO) is developed to generate an appropriate CPP site for the project owner and design an efficient site layout plan for the specialty subcontractor. The reconciling strategy is able to settle an agreement between the project owner and the subcontractor. To validate the applicability of the proposed method, a being-constructed CPP in China is used as a case study. The results demonstrate that it is an effective, robust and systematic method for decision makers to conduct a proper spatial analysis.

1. Introduction and literature review

To support a series of agricultural, industrial and domestic activities, the energy demand is increasing all over the world. Although renewable energy systems are environmentally safer than conventional energy systems, coal, gas and oil-fired thermal power remains to be one of the most important sources for electricity generation in many developing countries (e.g. China and India) [1,2]. In China, coal-fired power plants (CPPs) are established to generate 60–70% of the total thermal power, which are still expected to be the main source for future electricity generation for another 20–30 years [3]. According to the First Version of China Thermal Power Industry White Paper Series Book, until 2016, 592 CPPs are still being built for electricity generation in China. In addition, a large quantity of CPPs are been expanded to

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meet the energy demands at the local community level.

One main drawback of coal-fired energy systems is that they produce a significantly larger amount of environmental pollution than green energy systems, in particular the greenhouse gas emission. Under these circumstances, environmental issues caused by CPPs are attracting more attention from both the Chinese government and the local community. The present major environmental issues include climate change, noise pollution, environmental degradation and resource depletion. According to the Public Service Commission, various activities are able to cause environmental impacts during a CPP construction [4], including site preparation (e.g., clearing and grading), facility construction (e.g., pipelines, transmission lines), as well as vehicular and pedestrian traffic. For example, the CPP construction will have negative effects on 15–25 acres of land; one mile of transmission line construction would disturb about one acre of land [4]. Therefore, it has become a major challenge in China to protect the environment without hindering economic development [5].

There are a variety of studies in the literature emphasizing that the environmental impacts can be reduced by conducting a proper spatial analysis, including a site identification, a suitable site selection and an appropriate site layout. In other words, the geographical location of a thermal energy system would impact the environmental and economic feasibility of a energy supply system. For example, Choudhary and Shankar [1] deal with environmental concerns in the site selection process of a thermal power plant. Wu et al. [2] attempt to achieve an environmental goal by designing a site selection framework. Xu et al. [3] address the fact that the final selection of a power plant site has a vital impact on the environmental pollutants. Aydin et al. [6] focus on the great impact of site selection on the environmental and economic feasibility and propose a GIS-based site selection methodology. An empirical analysis is conducted by Mann et al. [7] to explore the spatial relationship between the energy supply system and transmission lines or pedestrian traffic. Based on the fact that the geographical variations of a site may lead to variations in noise pollution, Morrison and Sinclair [8] develop a wind energy system for a site selection. In addition, Punt et al. [9] take spatial characteristics into consideration and propose an integrated model to comply with economic and environmental concerns for a sustainable energy system. These studies validate the fact that the spatial analysis of a power plant impacts the environment, and a good spatial analysis influences the reduction of environmental pollutants and the achievement of a sustainable energy system.

Therefore, apart from abiding by stringent regulations set by the government or local agencies and restoring damaged areas after completing construction activities, to supply power cost-effectively and environment-friendly, *the primary consideration is to identify CPP potential feasible sites (PFSs), select a site and design a layout plan* that are conducive for the following construction difficulties (e.g. concrete pouring, hazardous materials transportation, and project scheduling) [1,10], as shown in Fig. 1.

It is a challenging and complicated task to conduct an integrated spatial analysis of site identification-selection-layout plan that is economically, socially and environmentally favorable to a CPP. CPP site identification-selection is a significant strategic decision and a successful CPP site selection is conducive for economic criteria, security issues, regional development, environmental protection and sustainability issues [1,3,10,11]. As CPPs are commonly built in areas with geographical and topological difficulties, various factors (e.g., geology network, power supply network and fuel supply network) are needed to be considered in the PFS identification process. Under these circumstances, we used the GIS technique from [3] to identify PFSs based on its good search capacity. Along with a successful CPP site selection, construction site layout planning (CSLP) is another task of the fundamental spatial analysis that is closely related to construction costs, construction quality and operation efficiency of a thermal energy system. Various techniques (e.g. heuristics [12,13], expert systems [14] and mathematical optimization techniques [15–18]) have been proposed to generate efficient layout plans based on project-by-project characteristics. In this context, CSLP is defined as locating permanent and temporary facilities on the construction site to facilitate other construction operations [16]. In mega or large-scale CPP construction projects, the project owner are responsible for decisive issues about financing, site identification and selection as well as other conditions; and subcontractors are contracted to implement highly specialized subprojects (such as CSLP, tunnel construction) [19]. In most CPP projects, the CPP project owner identifies PFSs and finalizes a site, and a subcontractor (e.g. Electric Power Design Institute) is contracted to design a site layout for all permanent and temporary facilities (as shown in Fig. 1). An efficient site layout plan is able to save up to 15% of the total construction costs and reduce environmental pollution [20]. *In the practical spatial analysis for an energy system, the CSLP presents a high reliance on the site selection factors, such as roads, fuel supplies and land use; contrarily, the CSLP, in particular the locations of permanent facilities, influences the site selection greatly by changing the economic, environmental and safety criteria.* To ensure a successful and smooth contract between the project owner and the CSLP subcontractor, the CPP site selection problem and the CSLP problem need to be considered concurrently in the spatial analysis process for a "win-win" solution that is satisfactory for both decision makers and economically and environmentally favorable for the coal-fired power system. *However, previous research presents the following limitations: (1) neglects the significance of spatial analysis (i.e. site selection and layout planning) on the reduction of environmental pollution and the development of thermal energy systems;* (2) neglects the mutual interdependencies (as explained in Section 2 in detail) of the CPP site selection and the CSLP processes; (3) neglects the uncertainty in the site selection-layout planning processes. To bridge the research gaps, our objective is to develop a new methodology to guide a practical spatial analysis for energy systems, including site selection and layout planning.

In real-world CPP projects, conflicts are inevitable when multiple contractors and subcontractors are involved in various construction operations[21]. In this context, conflicts are defined as any actions or circumstances that are caused by incompatible or opposing needs [22]. If the conflicts are not reconciled or resolved, the adverse relationships will jeopardize the ongoing collaborative construction operations [23–26]. In order to reconcile conflicts of various decision makers for the respective optimizations, the bi-level modelling technique has been validated to be a competitive and feasible tool, which has been applied in many applications and gained significant results. For example, Anandalingam and Apprey [27] reconcile the conflicts of an arbitrator and project owner by using a multi-level programming method. Gang et al. [28] establish a bi-level model to address the conflicts of a local government and several stone enterprises in a hierarchical structure. Min and Guo [29] establish an equilibrium model to compromise the conflicts between a carrier and a shipper for a better transportation network. A bi-level multiobjective optimization model is proposed to design and operate a mill simultaneously [30]. Ma and Xu use a bi-modelling technique to address the interdependencies of multiple decision makers [31]. All these excellent studies provide a fundamental basis to obtain a "win-win" solution for decision makers by establishing a bi-level model. In the model, both decision makers attempt to optimize their decisions and goals (i.e. maximizing the environmental and economic criteria) under some practical constraints and the interactions of each other. *Accordingly, we propose a bi-level modelling technique-based reconciling strategy to guide the project owner and the specialty subcontractor to reconcile the decision conflicts and get a better site selection-layout result.* The simultaneous optimization of site selection and layout planning will contribute to the spatial analysis, and thus benefits the reduction of environmental pollution and the achievement of a sustainable energy system indirectly.

To establish a bi-level model to resolve the mutual relationship of decision makers for an integrated CPP site selection-layout plan, more issues are needed to be addressed: first, both CPP site selection problem