Electrical Power and Energy Systems 100 (2018) 287–298

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Planning of integrated energy-environment systems under dual interval uncertainties

Gongchen Li[a], Wei Sun[a,c,*], Guo H. Huang[a,**], Ying Lv[b,***], Zhenfang Liu[a], Chunjiang An[d]

[a] Institute for Energy, Environment and Sustainable Communities, University of Regina, Regina, Saskatchewan S4S 0A2, Canada
[b] MOE Key Laboratory for Transportation Complex Systems Theory and Technology, Institute of Transportation System Science and Engineering, School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China
[c] Department of Water Resources and Environment, School of Geography and Planning, Sun Yat-sen University, Guangzhou 510275, China
[d] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec H3G 1M8, Canada

ARTICLE INFO

Keywords:
Greenhouse gas
Mitigation
Energy-environment systems
Regional scale
Uncertainty
Dual interval

ABSTRACT

Energy-related activities are closely linked with greenhouse-gas (GHG) emissions. Such emissions should be managed through incorporating the issues of GHG mitigation within the framework of energy-environment systems planning. However, a variety of uncertain information exists in such an integrated management system, commonly expressed as intervals and dual intervals. In addition, dynamic characteristics associated with system expansions are also an important issue that needs to be addressed. Therefore, a dual-interval mixed-integer linear programming (DMLP) model is proposed and applied to the planning of integrated energy-environment systems (IEES) when GHG-emission mitigation is considered. The DMLP-IEES model integrates interval programming, dual interval programming and integer programming. The model can handle both uncertainties presented as discrete intervals, and dual uncertainties without distribution information but rough estimations of lower and upper bounds. The applicability of the developed model is demonstrated by a case study at a regional scale. The results show that the DMLP-IEES model can use the available dual uncertain information more efficiently and the solved decision variables in dual intervals have more robustness and decision flexibility than traditional methods.

1. Introduction

Considerable concerns have been expressed about greenhouse gas (GHG) emission abatements in the past decades [2,4,9,28,46]. It is widely accepted that the issue should be incorporated within the energy-environment systems management [3,5,10,18,24,30,33,47,52,51,53]. In such a system, many energy activities need to be considered, such as energy production, energy import, energy storage, electricity conversion, power transmission, energy consumption and capacity expansion. These complexities can be further multiplied by varying economic, environmental, geographic, legislative and political conditions, such as rising energy prices, shrinking energy reserves, increasing environmental concerns, and emerging national/international protocols or obligations [7,49]. Consequently, a systems-analysis approach is desired for comprehensively planning such energy systems that are associated with actions for GHG-emission control.

To support regional energy-environment systems planning, numerous programming methods have been developed [1,8,15,17,18,21,23]. For example, Lehtilä and Pirilä [33] presented a bottom-up energy system optimization model (Finnish EFOM model) to support policy planning for sustainable energy use in Finland. Cormio et al. [15] proposed a bottom-up energy system optimization model based on the energy flow optimization model (EFOM) for renewable energy planning, and applied to the Apulia region in Southern Italy. Hashim et al. [20] developed an optimization model based on a MILP method for energy/CO_2-emission planning and applied it to Ontario Power Generation facilities in Canada. Becerra-Lopez and Golding [6] carried out a capacity expansion planning for regional power-generation systems of west Texas with a multi-objective optimization method. Ordorica-Garcia et al. [50] proposed an energy optimization model for the energy industry and government sectors of Canada. Hiremath et al. [22] proposed a goal programming-based model for decentralized sustainable energy planning in Tumkur District of India. However, most of these models are based on deterministic methodologies. They may not be able to reflect the uncertainties

* Corresponding author at: Institute for Energy, Environment and Sustainable Communities, University of Regina, Regina, Saskatchewan S4S 0A2, Canada.
** Corresponding author.
*** Corresponding author.
E-mail addresses: sunwei@iseis.org (W. Sun), guohe.huang@hotmail.com (G.H. Huang), ylv@bjtu.edu.cn (Y. Lv).

https://doi.org/10.1016/j.ijepes.2018.02.033
Received 8 August 2017; Received in revised form 6 December 2017; Accepted 18 February 2018
0142-0615/

that commonly exist in many real world cases [35,60].

To further reflect uncertainties in regional energy-environment systems planning, a series of programming models under uncertainty have been developed [60,13,11,37,42,55,12]. Some parameters with rich information can be presented as continuous/discrete stochastic distributions [18,19,29,32]) or fuzzy distribution [25,35,61], while the others with less information can be presented as interval formats [38]. Some models can reflect a single type of uncertainty [18,32,38], while the others may incorporate several types of uncertainties and complexities [25,34,39,62,63,64]. Although these models have provided certain measures for dealing with specific uncertain issues in power or energy systems, certain types of uncertainties could not be reflected due to the capability restrictions of these methods.

Especially, dual interval uncertainties, where no probabilistic distribution information but the rough estimation of the lower and upper bounds is available, have not been well addressed in energy-environment systems management. This type of uncertainty contains more information (showing the possibilities of the value within the range) than a single interval that could be addressed by interval-parameter programming. Nevertheless, it does not contain information as rich as a probability distribution which could be tackled by stochastic programming [58]. As a result, the interactions among environment, policy and economic aspects of integrated energy-environment systems (IEES) could not be reflected adequately. Dual-interval programming has been applied to waste and water resources management [43,41]. Few studies on application of dual-interval programming to IEES are reported. Thus it would be desired that a suitable IEES model under dual uncertainties be addressed.

This study is aimed at development of a model of dual-interval mixed-integer linear programming for energy-environment systems planning (DMLP-IEES). It entails: (i) the development of an IEES planning model to address interactions among energy resources allocation, power conversion, facility expansion and GHG-emission control, (ii) the integration of interval linear programming (ILP), dual interval linear programming (DILP) and integer programming (IP) techniques into a general planning framework, and (iii) application of the developed DMLP-IEES to a hypothetical case for energy systems planning and GHG-emission management under dual interval uncertainties.

2. Methods

2.1. Model development

Within a typical IEES, activities may include energy supply, conversion, and consumption as well as GHG emission, each of which also involves multiple components. Various energy resources are required to be allocated to different energy conversion technologies and demanding sectors within a multi-period horizon. The complexities of the IEES can be further compounded by these factors: (a) a number of environmental (e.g. GHG emission) and socio-economic (e.g. carbon tax and GHG-emission credits trading) issues are embedded within energy management systems; (b) technical and economic relationships among different energy sectors (supply, conversion and consumption) are complex; (c) dynamic interactions among various energy-related factors exist in a multi-period context; and (d) various uncertainties exist in processes of energy supply, conversion and consumption, as well as GHG emission.

The management problem of the IEES could be formulated as minimizing the expected value of the system cost with optimal schemes for energy allocation, energy conversion, capacity expansion and GHG-emission management. Energy allocation generally involves renewable energies (e.g. hydro, wind and solar) and non-renewable energies (e.g. coal, natural gas, diesel, gasoline and nuclear) in the IEES (Fig. 1). Most of these energies come from the local energy market, with a portion of energies, which are transportable or transmittable (e.g. coal, natural gas, diesel, gasoline and electricity), may come from adjacent regions. Based on various energy policies, demand projections for energy resources in every end-user sector can be acquired. Renewable energy resources and some non-renewable ones (e.g. coal and nuclear energy) are mainly utilized after their conversion into electricity. Besides, a portion of electricity can also be generated from natural gas-fired power plants.

Normally, generation facilities in the system have overall-cumulative limits while regional demands are flexible. If the demands do not exceed the existing capacity-limits of the corresponding facilities, sufficient electricity could be generated based on the available capacities. This will result in a regular system cost. Otherwise, if a large gap exists between the existing capacities and the regional demand, capacity expansion options need to be considered, resulting in extra costs [7]. Meanwhile, the GHG emission may also bring a certain amount of cost to the system, when economical GHG-emission abatement solutions (e.g. charging carbon tax and/or conducting GHG-emission credits trading) are adopted in the system planning. Since different types of energy resources may have varied GHG-emission coefficients, energy resources with high GHG emissions will be restricted (e.g. coal), leading to a trade-off between utilization of low-cost energy resources and high GHG-emission management costs. Thus, the decision maker needs to identify desired patterns of energy flow and facility expansion with a minimized system cost.

In addition, the majority of available information cannot be presented as deterministic values. Only the lower and upper bounds of parameters instead of the possibilistic and/or probabilistic distributions might be estimated. As those highly uncertain parameters may cause uncertainties in the lower and upper bounds of the intervals, dual interval uncertainties (i.e. interval-boundary intervals) can be appropriately presented. For instance, as extreme weather conditions and other emergent events may bring about further uncertainties. DME_t (allocated amount of electricity for municipalities) may roughly be [a, c] to [d, b] PJ (Fig. 2). The interval bounds [a, c] and [d, b] of the dual interval [[a, c], [d, b]] represent the uncertainties in the lower and upper bounds of a single interval. No distributional information is assumed to be available between a and c, between d and b and between [a, c] and [d, b] [40,41]. This variable could be presented as $[DME_t^{\pm}]^{\pm}$.

Thus, in the objective function of the DMLP-IEES, the total system cost is minimized, including costs for various energy-supply options, technology alternatives along with energy flows from supply side to demand end and compensations for GHG emissions. The methods of integer programming (IP), interval linear programming (ILP) and dual interval linear programming (DILP) will be combined into the DMLP-IEES. The IP approach is developed for quantifying facility expansion. The ILP method is used to handle the uncertain parameters expressed as interval numbers (with known lower and upper bounds but unknown distributions). The DILP methodology is employed to deal with the dual interval issues. Thus, the complexities that exist within and between individual sectors/processes of an energy-environment system can be effectively handled; energy resources to different demanders and technologies can be effectively allocated; related facility expansion schemes can be formulated; and competitions among energy resources, power-generation technologies, and GHG-emission mitigations can be comprehensively considered. The formulation of the DMLP-IEES model is as follows: