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Uncertain network data envelopment analysis with undesirable outputs to evaluate the efficiency of electricity power production and distribution processes

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ABSTRACT

In this paper, a customized network data envelopment analysis model is developed to evaluate the efficiency of electric power production and distribution processes. In the production phase, power plants consume fuels such as oil and gas to generate the electricity. In the distribution phase, regional electricity companies transmit and distribute the electricity to the customers in houses, industries, and agriculture. Although, the electricity is assumed to be a clean type of energy, several types of emissions and pollutions are produced during electricity generation. The generated emissions are considered as an undesirable output. A customized network data envelopment analysis (NDEA) approach is proposed to evaluate the efficiency of these processes Each decision making unit (DMU) includes two serially connected sub-DMUs, i.e., production and distribution stages. The models are extended using interval data to address the considerable uncertainty in the problem. The efficiency scores of main process, and each sub-process are determined. The final ranking of DMUs and sub-DMUs are achieved using a multi-attribute decision making (MADM) method. The whole approach is applied in a real case study in electrical power production and distribution network with 14 DMUs. The proposed approach has the following innovations in comparison with existing methods: (1) Both production and distribution process are evaluated in a unique model; (2) Undesirable outputs and uncertainty of data are considered in proposed approach; (3) Properties of proposed models are discussed through several theorems; (4) The efficiencies of production and distribution phases are determined distinctively; (5) A full ranking approach is proposed; (6) A real case study of electrical power production and distribution network is surveyed. The results of proposed approach are adequate and interesting. This approach can be customized for application in similar systems such as water production-supply management, Oil and fuel production–distribution systems, and supply chains.
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1. Introduction

Electrical power is an essential infrastructure for most to the all of industries, services, and productions. The electrical power has an important role in economic development and improving people's life. Electrical power industry consists of production, distribution, and transmission. Thus, identify and assess the performance of each segment can be used to improve the entire industry. Electrical network consists of producing and distributing phases. In the production phase, power plants consume several types of fuels, bio-mass, of solar heat to produce the electricity power. In the distribution phase electricity power is as an input for regional transmission electricity companies. In this phase, electricity power received from production phase and electricity power received from the other regional power companies are as input for regional electricity companies. These companies act to the transmission and distribution of electricity power to other neighboring companies and distributor companies and users in industry, service, and homes. The relations between production centers, distribution centers, regional power companies, and several types of users of electrical power forms a complicated network structure. The value of inputs and outputs in such network is not deterministic due to several issues. So, a considerable amount of uncertainties are mixed with data. Moreover, the production of electrical power is mixed with generation of pollutions and emissions which are called undesirable outputs. The purpose of this paper is to answer the following question:

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How can to measure overall efficiency such complicated electrical power networks in presence of undesirable outputs, uncertainties and interactive relations?

What segments in such networks are efficient, and what elements are inefficient?

Several issues exist in electrical power generation and distribution networks. There are multiple inputs and outputs in such networks, undesirable output such as amount of emissions released from the production process, lack of assumption about the production function (Lin & Tzeng, 2005), uncertainty in data, network structure, and internal relationship in production and distribution phases, make the evaluation of the efficiency of such networks a hard job.

Considering the above assumption, one of the well-known non-parametric methods called, data envelopment analysis (DEA) is used in this study. DEA was originally introduced by Charnes, Cooper, and Rhodes, 1978. DEA is based on mathematical programming to measure the relative efficiency of homogenous decision making units (DMUs) with multiple inputs and outputs. The theoretical aspects of DEA approach has been extended in many areas such as network structure in DEA (Fare & Grosskopf, 2000; Lewis & Sexton, 2004; Zhu, 2009), two-stage DEA (Chen & Zhu, 2004; Chen, Liang, Yang, & Zhu, 2006; Chen, Cook, Li, & Zhu, 2009; Cook, Liang, & Zhu, 2010; Kao and Hwang, 2008; Liang, Cook, & Zhu, 2008), presence of undesirable factors (Ali & Seiford, 1990; Amirteimoori et al., 2006; Fare, Grosskopf, Lovel, & Pasurka, 1989; Jahanshahloo, Hadi-Vencheh, Foroughi, & Kazemi-Matin, 2004; Koopmans, 1951; Seiford and Zhu, 2002; Zavadskas, Zakarevicius, & Antucheviciene, 2006), qualitative data (Cook & Hababou, 2001; Cook, Hababou, & Tuenter, 2000; Cooper, Seiford, & Zhu, 2004; Khalili-Damghani & Tavana, 2013; Kim, Park, & Park, 1999; Zhou, Ang, & Poh, 2006).

In this paper, a customized network data envelopment analysis model is developed to evaluate the efficiency of electric power production and distribution processes. Electric power production and distribution network conforms of generating and distributing the electric power serially. In the production phase, power plants consume fuels such as oil and gas to generate the electricity. In the distribution phase, regional electricity companies transmit and distribute the electricity. Although, the electricity is assumed to by a clean type of energy but there generate several types of emissions and pollutions during generation. The emissions released from the production process are considered as an undesirable output in this study. For evaluating the efficiency of above processes, a customized network data envelopment analysis (DEA) approach is proposed. Each decision making unit (DMU) has been supposed to make up of two serially connected sub-DMUs: i.e., production stage and distribution stage. As the data are mixed with considerable amount of uncertainty the proposed approach is developed using interval data. The final ranking of DMUs and sub-DMUs are achieved using an MADM method, called TOPSIS. The whole approach is applied on a real case study in electrical power production and distribution network in IRAN consisted of 14 DMUs during time period 2006–2012. The proposed approach has the following innovations in comparison with existing methods: (1) both production and distribution process are evaluated in a unique model; (2) undesirable outputs and uncertainty of data are considered in proposed approach; (3) the efficiency of each phase (i.e., production and distribution) have determined distinctively; (4) a full ranking approach is considered in proposed approach; (5) a real case study of electrical power production and distribution network is surveyed using proposed approach. The results of proposed approach show its applicability in similar systems such as water supply management systems and fuel systems.

The remainder of the paper is organized as follows. In Section 2, a review of past literature are presented. In section 3, the customized network data envelopment analysis model is developed to evaluate the efficiency of electric power production and distribution processes with undesirable output in presence of uncertainty. In section 4, the proposed approach is applied on a real case study of electrical power production and distribution network in Iran and results are also discussed. In section 5, we discuss our results and future research directions.

2. A brief literature review

2.1. Two-stage and network DEA

Although DEA is capable to achieve relative efficiency scores of DMU, it is not able to consider the internal processes in a DMU. On the other hand, when measuring the efficiency, we may interest in allocating efficiency and inefficiency to the internal process in a DMU. There are several research in the literature of DEA which tried to enhance this pitfall using different perspectives. Kao and Hwang (2008) considered the series relationship of the two sub-processes and showed the overall efficiency was product of the efficiencies of two sub-processes. They also evaluated the efficiency of the non-life insurance companies with relational and independent two-stage DEA model and compared the results. Li, Chen, Liang, and Xie (2012) extended the Liang et al. (2008) approach. Li et al. (2012) considered a two- stage DEA model in which the outputs of the first stage and additional input to second stage were assumed as inputs of the second stage. Moreno and Lozano (2014) presented a network DEA model for the evaluating the efficiency of NBA teams. Moreno and Lozano (2014) also compared the results with single stage DEA approach.

2.2. Mathematics of two-stage DEA with additional input to second stage

Fig. 1 shows the classic two-stage network DEA structure. Each DMU consists of two serially connected sub-DMU. The outputs of first stage are assumed as inputs of second stage and no extra inputs exist in second stage (Kao & Hwang, 2008). Each $DMU_j (j = 1, \ldots, n)$ has m inputs called $x_{ij} (i = 1, \ldots, m)$ and D outputs called $z_{dj} (d = 1, \ldots, D)$ in the first stage. The outputs of first stage is assumed as inputs of second stage. They are called intermediate measures. There are r outputs called $y_{rj} (r = 1, \ldots, s)$ for the second stage. In this structure, outputs from first stage are just as inputs to second stage. Overall efficiency is product of the efficiencies of two sub-processes. The mathematical model for Fig. 1 has been widely discussed in the literature (Kao & Hwang, 2008). We do not present it again for sake of brevity.

Fig. 2 presents a type of two-stage network structure in which in second stage some extra inputs are seen (Liang et al., 2008). In the structure shown in Fig. 2 there are also h inputs called $x^2_{hj} (h = 1, \ldots, H)$ to the second stage.

These measures are called additional inputs. Model (1) is proposed in order to measure the relative efficiency of network structure shown in Fig. 2 (Li et al., 2012).

$$\begin{aligned}
&\theta^{cen} = Max\theta_1^o \times \theta_2^o = Max \frac{\sum_{d=1}^{D} w_d z_{do}}{\sum_{i=1}^{m} v_i x_{io}} \times \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{d=1}^{D} w_d z_{do} + \sum_{h=1}^{H} q_h x^2_{ho}} \\
&\text{s.t.}\ \frac{\sum_{d=1}^{D} w_d z_{dj}}{\sum_{i=1}^{m} v_i x_{ij}} \leqslant 1,\ j = 1, \ldots, n; \\
&\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{d=1}^{D} w_d z_{dj} + \sum_{h=1}^{H} q_h x^2_{hj}} \leqslant 1,\ j = 1, \ldots, n; \\
&w_d \geqslant 0,\ d = 1, \ldots, D; \\
&q_h \geqslant 0,\ h = 1, \ldots, H; \\
&v_i \geqslant 0,\ i = 1, \ldots, m; \\
&u_r \geqslant 0,\ r = 1, \ldots, s.
\end{aligned} \tag{1}$$

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