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Research Paper

# A risk averse cross-efficiency data envelopment analysis model for sustainable switchgrass cultivation location optimization

Hossein Khanjarpanah, Mir Saman Pishvaee*, Seyed Mohammad Seyedhosseini

*School of Industrial Engineering, Iran University of Science and Technology, Narmak, Tehran 1684613114, Iran*

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ABSTRACT

Environmental concerns and energy security have led to growing interest to second-generation biofuel production from non-edible feedstock such as switchgrass. In this article, sustainable and ecological indicators are introduced to evaluate the candidate locations efficiency for switchgrass cultivation. To optimize the candidate locations, a novel data envelopment analysis (DEA) cross-efficiency model is proposed which attempts to maximize output worst-cases of all candidate locations. Moreover, in order to consider both mean and standard deviation of candidate locations cross-efficiencies, a new ranking measure is presented. The performance of proposed model is investigated in comparison with several models through a real case study in Iran. The efficiency values of Iran provinces are calculated by several DEA cross-efficiency models. The numerical results show that proposed model manages to evaluate the candidate locations efficiency more moderate than other models. Besides, the standard deviation of cross-efficiencies for this model are lower than that of other models. The obtained findings from introduced DEA model reveal that based on the defined ranking measures, Khouzesan and Fars provinces are non-dominate locations for switchgrass cultivation.

## 1. Introduction

The extensive fossil fuels use has led to increase air pollution, climate changes, global warming, food crisis, volatile fuel prices and fossil fuel resource depletion. Moreover, until 2030, the current demand of energy will be enhanced 50% and liquid fuels would be the most required fuel type (Babazadeh et al., 2016). Transportation sector has the major share of energy demand among the various demanding energy sectors. Hence, seeking for sustainable and reliable sources of energy has high importance. Biofuel can be counted as an alternative for fossil fuel in transportation sector. In the recent years, biofuel has absorbed the attentions due to its environmental benefits. Biofuels usage gives rise to reduction in dependence on fossil fuel. Furthermore, second generation biofuel does not compete with agriculture products in cultivation lands. On the other hand, rural development in cultivation regions is attributed to using lignocellulosic biomass. It is worth mentioning that if the sequestered carbon amount to be greater than the lost amount during harvest, production, and feedstock transportation to facility, the biofuel production will be carbon negative. Carbon negative biofuel production led to climate change by eliminating excess carbon from atmosphere and serve as renewable energy source instead of fossil fuels (Tilman et al., 2006).

Research interest of bioenergy is increased to meet the vision of 30% replacement of US current petroleum consumption with biofuels until 2030 using approximately 1 billion dry tons sustainable annul production of biomass feedstock (Perlack et al., 2005). In the past years, biofuel production from switchgrass has become possible (Qin et al., 2006). Switchgrass is a perennial warm-season grass which is one type of lignocellulosic feedstock that can be cultivated on marginal lands without any competitions with edible agricultural products land (Sokhansanj et al., 2009). It is valuable to say that the effect of soil type on switchgrass productivity is not significant in comparison with the other grasses (Hartman et al., 2011). Switchgrass is one of the best second generation bioethanol feedstock due to its benefits such as low production cost, low water consumption, adaption to several environments, need for low soil nutrient, capability for improving soil conservation, high net energy obtained from cultivated land unit, greenhouse gases (GHG) emissions reduction and economic development of rural areas (Mclaughlin and Walsh, 1998). Switchgrass is a native North America plant and can be cultivated in different world regions (Lewandowski et al., 2003; Van Dam et al., 2009; Ma et al., 2011). In addition, different species are existed for switchgrass (Casler et al., 2004) and this variability in species led to the extensive adaptation across a varied environmental conditions (Parrish and Fike, 2005). Switchgrass can grow in low nutrient land with some normal climate condition such as 5–25 °C mean annual temperature amount and

* Corresponding author.
*E-mail addresses:* khanjarpanah@ind.iust.ac.ir (H. Khanjarpanah), pishvaee@iust.ac.ir (M.S. Pishvaee), seyedhosseini@iust.ac.ir (S.M. Seyedhosseini).

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250–1500 mm mean annual precipitation amount (Hartman et al., 2011).

Recently, the cultivated areas of switchgrass have been increased due to sustainable benefits of this feedstock. Therefore, location optimization of the candidate areas for switchgrass cultivation is an essential problem. Cultivation location problem includes modeling, formulation, and solution of the problem. This problem sets out to determine the best candidate lands for cultivation. Usually, different indicators can effect on the location problem and this problem has multiple objectives. Multiple criteria decision making (MCDM) methods have been used in order to consider different criteria for cultivation location problem. This paper uses data envelopment analysis (DEA) as an efficient optimization based mathematical programming method to made decision about switchgrass cultivation areas.

To the best of our knowledge, there is no comprehensive study in the relevant literature about sustainable switchgrass cultivation location optimization problem by using DEA model. Accordingly, this paper proposes a novel DEA cross-efficiency model to evaluate the efficiencies of the candidate locations for switchgrass cultivation, which is capable of capturing output worst-cases of all candidate locations and tries to maximize all of them. Against the common cross-efficiency models such as aggressive, benevolent, and neutral, this model considers all decision making units (DMUs) in each repetition for evaluation at its objective function. Afterwards, due to importance of average and standard deviation values of obtained cross-efficiencies, a new measure related to DEA cross-efficiency model is introduced for ranking of the candidate locations that takes into account both average and dispersion of DMUs performance. Ecological and sustainable indicators are presented to assess the performance of candidate locations for switchgrass cultivation. Iran provinces are chosen as case study in order to illustrate the performance of the proposed model in comparison with common models that try to minimize or maximize the performance of all the DMUs except the considered DMU which are known as aggressive and benevolent models, respectively. The rest of this paper is structured as follows. In the next section, the previous related works are reviewed. The proposed DEA cross-efficiency model and index are introduced in Section 3. Section 4 provides the sustainable criteria and the case study results. Finally, the paper is concluded in Section 5 and some attractive future research directions are presented.

## 2. Literature review

A growing literature is dedicated to biofuels production and its feedstock. One type of lignocellulosic feedstock is switchgrass that can be cultivated on both marginal and arid lands, without any competitions with other agricultural or edible crops. In recent years, different aspects of switchgrass have been studied and investigated in literature, including harvesting (Cahill et al., 2014), soil condition (Haque et al., 2014; Zaibon et al., 2017), environmental effects (Zhou et al., 2015), life cycle assessment (Bichraoui-Draper et al., 2015), ecological and environmental impacts (Hartman et al., 2011; Ashworth et al., 2015; Wang et al., 2015), and supply chain (Kaliyan et al., 2015; Yu et al., 2016; Zhang et al., 2013).

One of the main decisions in biofuel production systems is determining the optimal location for cultivation of used feedstock. This decision making is placed in strategic level and the feasibility of biofuel production project is related to it (An et al., 2011). However a lot of criteria effect on the optimal location of feedstock cultivation land, most of studies have considered only the economic or cost criterion (Leduc et al., 2010; Gan and Smith, 2011; Andersen et al., 2012; Ng et al., 2013). Cultivation location of feedstock is dominated by environmental and social criteria such as amount of rainfall, daily temperature, population, human development index, and etc. (Babazadeh et al., 2016). Hence, it is essential to consider environmental and social criteria in addition of economic indicators to guarantee the sustainable yields of feedstock. The major part of biofuel production costs is associated with feedstock costs (Bozbas, 2008). Consequently, determining the optimal land for feedstock cultivation by considering environmental, social, and cost criteria can conclude the viability of biofuel production projects. Despite the importance of determining switchgrass cultivation location, there are not sufficient papers devoted to this matter.

DEA is a non-parametric method for evaluating and comparing DMUs relative efficiency that is based upon the works of Farrell (1957) and Charnes et al. (1978). Disregarding the internal operations of DMUs can be counted as one of the DEA model advantages (Hatami-Marbini et al., 2011) and also, multiple inputs and outputs can be handled by this model. DEA classifies the DMUs into efficient and inefficient ones. Since the proposed DEA by Charnes et al. (1978), there has been a continuous development in both theoretical and applications of this method. Hence, a significant amount of bibliographies have published in DEA literature, such as (Adler et al., 2002; Emrouznejad et al., 2008; Cook and Seiford, 2009; Hatami-Marbini et al., 2011; Song et al., 2012; Sueyoshi et al., 2017).

Banker et al. (1984) proposed a model under variable return to scale (VRS) condition, while Charnes et al. (1978) have considered model under constant return to scale (CRS) condition. After CRS and VRS models, additive model has introduced by Charnes et al. (1985) which combined both input and output orientations. Also, some non-radial models are proposed by Cooper et al. (1999), Tone (2001), Portela et al. (2003) and Sueyoshi and Goto (2011), and the others. Cross efficiency model is another extension of DEA, which in it, for a given DMU, technical efficiency scores can be evaluated with the optimal weights corresponding to each DMUs. The final cross efficiency score of DMU will be obtained by averaging of technical efficiency scores. This method was proposed by Sexton et al. (1986). Doyle and Green (1994) pointed out that optimal weights are not unique and it is possible to reduce the cross efficiency usefulness. To cope this problem, they considered secondary goals that was called aggressive and benevolent models. After introducing aggressive and benevolent models, neutral model proposed by Wang and Chin (2010) (For more information about DEA models taxonomy refer to (Cook and Seiford, 2009)).

DEA is a well-known methodology in energy and environment problems. Recently, Sueyoshi et al. (2017) have reviewed the previous research works (693 articles) on applied DEA to energy and environment. According to their work, the application of DEA in renewable energies problems has experienced a significant growth after 2010. DEA is applied on different renewable resources such as wind (Azadeh et al., 2011; Azadeh et al., 2014; Iribarren et al., 2014), solar (Lee et al., 2015, Sueyoshi and Goto, 2014), biomass (Grigoroudis et al., 2014; Babazadeh et al., 2015; Babazadeh et al., 2016), and other (Halkos and Tzeremes, 2013; Kim et al., 2015). By reviewing the previous researches, there is not a rich literature about DEA application in determining of feedstock cultivation location for biofuels. Babazadeh et al. (2015) investigated the application of DEA in location optimization of *Jatropha curcas* L. cultivation with considering the sustainable criteria. In their work, a non-radial DEA model was employed that was able to separate the outputs into desirable and undesirable ones. Further, Babazadeh et al. (2016) developed their previous work by proposing a unified fuzzy DEA (UFDEA). In their work, the uncertainty of sustainable criteria was considered and have coped with a UFDEA model.

Zhang et al. (2013) work is one of the few papers that has referred to determine the location of switchgrass cultivation. Their research is concentrated on commercialization of the switchgrass-based bioethanol production by design an efficient switchgrass-based supply chain. The research has presented an integrated mathematical modeling to make optimal supply chain decisions. North Dakota state in United States is considered as a case study for the application of the presented model. However the research has not focused on the switchgrass cultivation location concern, but decisions about cultivation location can be made in respect to minimize the total cost of considered supply chain with