ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

# The integrated efficiency of inputs–outputs and energy – $CO_2$ emissions performance of China's agricultural sector

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ARTICLE INFO

*Keywords:*
Agricultural sector
Integrated efficiency
Energy–$CO_2$ performance
Energy intensity
$CO_2$ emission reduction

ABSTRACT

This research aims at exploring the integrated efficiency of inputs–outputs and unified performance in energy consumption and $CO_2$ emissions for the Chinese agricultural sector, and also examining the reduction potential of energy intensity and $CO_2$ emission intensity in the sector. For this purpose, we adopt a non-radial directional distance function in this study. It incorporates the inefficiency of all input factors and desirable and undesirable outputs to estimate the integrated (operational and environmental) efficiency and energy–$CO_2$ performance of China's agricultural sector. An empirical research of 30 provinces in China is conducted by using the approach. The main practical conclusion follows: First, most of China's provinces and regions did not perform efficiently in input factors as well as the integrated efficiency of inputs-outputs and unified performance in energy consumption and $CO_2$ emissions in the agricultural sector. The average score of integrated efficiency and energy–$CO_2$ performance is 0.447 and 0.425 respectively within the sample period. Provinces in East China mostly performed better than those in Central and West China. Second, with slack and advanced production technology considered, there is vast energy-saving and $CO_2$ emission reduction in the Chinese agricultural sector. In theory, the reduction potential of energy intensity and $CO_2$ emission intensity can reach 59.6177% and 56.4948% respectively of the actual level. The central and western regions show great reduction potential of energy intensity and $CO_2$ emission intensity compared with the eastern region. Based on these findings, some policy suggestions for improving the integrated efficiency of inputs-outputs and unified performance in energy consumption and $CO_2$ emissions are provided for China's agricultural sector.

## 1. Introduction

China's economy has progressed greatly since the reform and opening-up policy started in 1978. According to the Nation Bureau of Statistic of China (NBSC), China's real gross domestic product has grown about a hundred times in 2012 more than the level in 1978. This fast-growing rate makes China the world's biggest economy according to International Monetary Fund [21]. However, such astonishing economic expansion is accompanied with large energy consumption. In 2013, China's energy consumption is 4.17 billion tons of standard coal, which is much greater than 571 million tons in 1978 [40]. The rapid industrialization and rigid demand for energy use make China the largest energy consumer in the word [4]. Over this time span, China's agriculture has also made tremendous strides in boosting economic development and improving the living standards of the people. It feeds more than 20% of the world's population using less than 10% of global arable land. Moreover, agricultural mechanization in China is currently rapidly and widely popularized, which leads to a significant increase in energy use and its related-$CO_2$ emission. During the period 2001–2012, agricultural output (at 1978 prices) increased from 571.07 billion yuan RMB in 1985 to 980.46 billion yuan RMB in 2012. This is mainly thanks to the implementation of the household contract responsibility system and the promotion of agricultural mechanization. The total mechanical power soared from 551.72 million kilowatt in 2001 to 1025.5 million kilowatt in 2012. It drove energy consumption increase from 43.45 to 74.44 million tons of standard coal equivalent; and as a result $CO_2$ emissions increased from 116.26 to 185.66 million tons during this period, as shown in Fig. 1. As a result, overuse of resources and environmental pollution has hindered the sustainable development of China's agricultural sector.

It is common sense that enhancing energy and environmental efficiency is a crucial and scientific way for the world to combat energy

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http://dx.doi.org/10.1016/j.rser.2016.11.040
Received 19 November 2015; Received in revised form 27 August 2016; Accepted 4 November 2016
1364-0321/ 

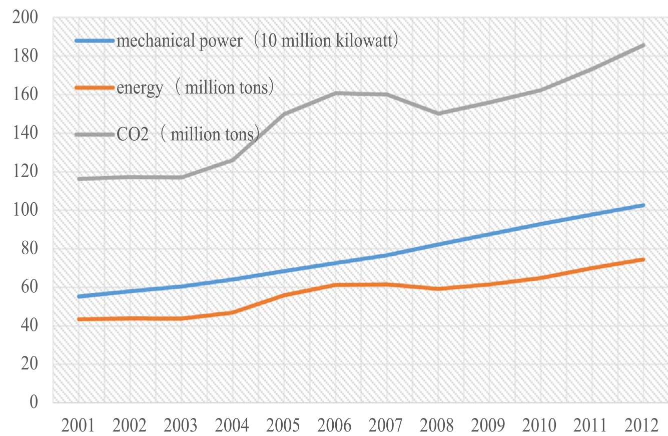


**Fig. 1.** Agricultural mechanical power, energy consumption and $CO_2$ emissions in China, 2001–2012.

and $CO_2$ challenge. Hence, accurate evaluation of energy input and environmental efficiency is of great importance. In many previous studies, they have adopted data envelopment analysis (DEA) technique to explore energy and $CO_2$ performance from a perspective of production efficiency ([22,23,32,37]). In the case of agriculture, there are also a lot of similar studies ([2,17,26,27,33,35,36,39,46]). In comparison to the traditional DEA models, DDF which proposed afterwards measures production efficiency by increasing desirable outputs (e.g., agricultural output) and reducing undesirable outputs (e.g., $CO_2$ emissions) at the same time. This is regarded as a radial efficiency measure with few shortcomings that it may overestimate efficiency when there exist some slacks [15] and cannot distinguish between environmental and operational performance [38]. Several papers have developed the conventional DDF into the non-radial directional distance function (NDDF) by incorporating slacks into efficiency measurement [1,13]. In recent years, Zhou et al. [49], Zhang et al. [44,45] and Lin and Du [28] used this method to measure performance in energy and $CO_2$ emission at the industrial and regional levels.

We use Fig. 2 to illustrate the differences between NDDF and the traditional DEA method. We consider the EDFC area as the production sets which describe the environmental production technology T. Suppose point M is the decision point and g is the policy directional vector. If we use the DDF method to estimate the efficiency of point M, point F is the benchmark to realize efficiency maximization. However, when we use the NDDF method to estimate the efficiency of point K, the benchmark is point D. It can be seen that, at point D, it can decrease more undesirable output while keep the desirable output constant. Thus, the distance DF is the non-zero slack of the undesirable output. In the DDF method, it does not take the non-zero slack into consideratio n, and as a result, it may underestimate the potentiality of the inefficiency.

The paper employed the NDDF based on Zhou et al. [49] and Zhang et al. [46] to explore the unified efficiency (operational and environmental efficiency) and energy–environmental performance of China's agricultural sector. Meanwhile, it also examines the reduction potential of energy intensity and $CO_2$ emission intensity during the studied period. Different from Zhou et al. [49], however, the paper considers energy factors as well as non-energy factors (capital and labor) because it focuses on exploring agricultural unified performance. To measure the unified efficiency, we propose a total-factor NDDF (TNDDF) that incorporates inefficiencies for all the input factors and desirable and undesirable outputs. Unlike Zhang et al. [45], when measuring energy–environmental performance, we still follow the same (TNDDF) without fixing non-energy inputs, because we want to measure the potential reduction of energy intensity and $CO_2$ emission intensity under the condition that all inputs and outputs are in their optimal states. According to what we have learnt, this paper is the first to empirically explore the unified efficiency and energy–environmental performance of China's agricultural sector. Using this method, we can estimate the reduced degree of input factors and $CO_2$ emissions in effective output.

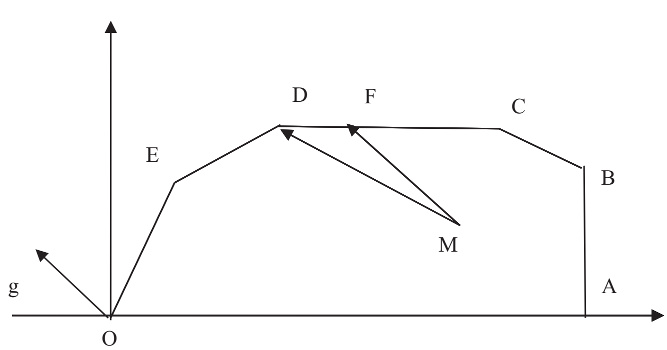


**Fig. 2.** The illustration of non-rational direction distance functions.

We take China's agricultural sector as a case study because it is an important and indispensable part of the economy and has contributed to increased energy consumption a lot in recent years. However, the quantitative impact of energy-related pollution treatment on the efficiency of the agricultural sector is still under-explored since agriculture makes smaller contribution to the national economy compared with the industrial and service sector [30]. This gap motivates us to explore the energy and environmental performance of China' agriculture sector, which can help policy makers in agricultural policy formulation.

The rest of the paper is as follows. In Section 2, the research methods and methodologies are illustrated on the whole. In Section 3, the data and variables are presented in details as well as the empirical results. In Section 4, the related discussion is further provided. Section 5 concludes this study and suggests policy implications in the paper.

## 2. Methodology and method

### 2.1. DEA modeling with undesirable outputs

As mentioned above, the DEA method is usually thought to be a popular tool in measuring energy and environmental performance [37,44,6]. There have been several approaches dealing with the undesirable output based on the DEA. The first category takes the undesirable outputs as input factors, and the representative literatures include Haynes et al. [19], Lee et al. [24], and Hailu and Veeman [18]. This method is easily grasped and operated by investigators and satisfies the requests that undesirable outputs are smaller. However, it is not consistent with the actual situation. The second one is conducting data transformation to undesirable outputs. Specifically, the undesirable outputs that are the-smaller-the-better are transferred to new variables treated as desirable outputs that are the-larger-the-better. Then the traditional DEA method can be employed to explore the efficiency of energy or the environment [20]. The third category distinguishes the weak and strong disposability between the undesirable and desirable outputs. Based on the joint-production framework, researchers and scholars have developed several models for assessing energy or environmental performances [8,14,43,44,48].

Among these measurements, the DDF method raised by Chung et al. has been largely used in empirical application, which allows for increase in desirable output and decrease in undesirable output and the input factors at the same time [12,3,31,34,10]. However, the DDF may underestimate the efficiency loss of the assessed DMU due to its radial efficiency measure [10]. Fortunately, Zhou et al. [49] developed a non-radial directional distance function (NDDF) method that allows for disproportional adjustments of input factors, desirable and undesirable outputs. Hence, the non-radial directional distance function (herein after referred to as NDDF) has a higher discriminating ability than the directional distance function DDF. Thereafter, this method is further