Journal of Applied Biosciences 173: 17963 – 17976
ISSN 1997-5902

Distance function approaches for efficiency analysis of organic production units: a critical review

Ceptime Ahlonsou[1*], Epiphane Sodjinou[2], Romain Glèlè Kakaï[1]
[1]Laboratoire de Biomathématiques et d'Estimations Forestières, Faculty of Agronomic Sciences, University of Abomey-Calavi Campus (LABEF/FSA/UAC), Building CBIG (2nd floor), Abomey-Calavi, O4 BP 1525 Cotonou, Benin.
[2] Faculté d'Agronomie, Université de Parakou, Parakou, Bénin
[*] **Corresponding author: E-mail:** aceptime@yahoo.com

Submitted on 22nd February 2022. Published online at www.m.elewa.org/journals/ on 31st May 2022
https://doi.org/10.35759/JABs.173.4

ABSTRACT
Objectives: This review aims to make a comprehensive synthesis of distance function methods for the efficiency analysis of organic production units.
Methodology and Results: The study reviewed and summarized the different approaches of distance functions applied in organic farming systems to assess performance. Original articles covering ten years, from 2010 to 2020 were identified through keyword searching using web search engines. After careful reading of the abstracts, 20 papers were finally retained. The selected papers were categorized based on study purpose and findings. Results showed a gap between the development of distance function methods and their usage in organic farming efficiency analysis. Four distance function methods were identified, and the most used in organic farming efficiency analysis were output distance function (40%) and directional output distance function (25%).
Conclusion and application of findings: Results indicate that distance functions are powerful tools in modelling multi-input and multi-output production technology for assessing organic farming efficiency. Future research should focus on these methods to deepen their understanding and applications.
Keywords: Distance function, efficiency analysis, literature review, organic farming.

INTRODUCTION
Modelling production technology through production function is one of the basic tools in the economic analysis of agricultural production. Over the years, the typical production function expressing a single output as a function of inputs, also known in the literature as a single-output production function, has been widely used by economists to analyse efficiency (Kalirajan and Shand, 1999). This gives good estimates when the farmer produces a single product using given inputs that are available to him following Färe and Primont (1990). In other words, performance estimates may be biased by using a single output production function in circumstances where the farmer produces more than one output, mainly because of the restrictive assumptions that must be imposed (Mensah and Brümmer, 2016). Moreover, agricultural productions are by nature heterogeneous and modeling outputs separately, in the same production function,

when evaluating farm performance seems more appropriate. Unfortunately, most studies ignore this heterogeneity of agricultural farm outputs and instead aggregate these outputs into a single variable for productivities and efficiencies assessment purposes (cf. Franksen and Latacz-Lohmann, 2006; Abdulai and Tietje, 2007; Franksen *et al.*, 2007; Lohr and Park 2010; Tiedemann and Latacz-Lohmann, 2011; Kellermann and Salhofer 2011; Mamardashvili *et al.*, 2014). The production of organic cotton, as promoted in Benin, is a typical example of multiple outputs and multiple inputs farm. Indeed, the farmer who engages in organic cotton production must see his farm as a system encouraging associations and crop rotations (cotton-legumes-cereals, for example). Thus, analysing the performance of cotton alone without considering the other crops in the farming system seems to deviate from reality. Therefore, analyzing the performance of such a farm requires the use of models that take into account multiple inputs and multiple outputs (see also Brümmer *et al.*, 2006; Mensah and Brümmer, 2016). An alternative to the use of production functions with one output in the analysis of the performance of production units is the use of distance functions that take into account several inputs and several outputs. This alternative, suggested by Shephard (1953, 1970), helps overcome problems related to the implicit assumptions imposed on a single production function (Zhang and Brümmer, 2011). Distance functions are more advantageous than single-output production functions since they: (a) require neither information on input prices nor the behavioural assumptions such as cost minimization, revenue maximization, and profit maximization and (b) allow researchers to directly obtain a measure of allocative inefficiency independent of the degree of technical inefficiency (Kumbhakar and Lovell, 2000; Brümmer *et al.*, 2002; Coelli *et al.*, 2005). The application of distance function methods in various fields is increasing (Coelli and Perelman, 1999) (e.g. Färe *et al.*, 1993; Lovell *et al.*, 1994; Grosskopf *et al.*, 1997). This is reflected by publications in various fields such as agriculture (including farming systems), environment, and energy. Many studies applied this methodology to analyse the technical efficiency and the technical change in European and American dairy farming sectors (e.g. Brümmer *et al.*, 2002; Newman and Matthews, 2006; Areal *et al.*, 2012; Mamardashvili, 2013; Mamardashvili *et al.*, 2014; Le *et al.*, 2020). Other studies applied this methodology to analyse the farming type of other crops such as wheat, cereal, grassland and citrus (e.g. Kamdem, 2012; Blancard and Martin, 2013; Beltran-Esteve and Reig-Martinez, 2014; Cechura *et al.*, 2014; Manevska-Tasevska *et al.*, 2014; Singbo *et al.*, 2014; Clemente *et al.*, 2015; Singbo *et al.*, 2015; Huang *et al.*, 2016; Beltran-Esteve *et al.*, 2017; Lakner *et al.*, 2018). The organic farming system is one of the main adopted production systems, which is based on the principle of environmentally sound production and allows to use efficiently natural resources (i.e. nutrient management, energy use, water efficiency.) (Stolze *et al.*, 2000; Bonou-zin *et al.*, 2019). It has been investigated and compared to conventional farming extensively using productivity and efficiency analysis (Lakner and Breustedt, 2017). However, given its advantages, a comprehensive overview and a summary of the literature on the efficiency and productivity of organic farming are missing (Lakner and Breustedt, 2017). In addition, although many research studies have focused on performance analysis using distance functions, only a few studies analysed organic farming production technology with multiple outputs and multiple inputs (e.g. Brümmer *et al.*, 2002; Newman and Matthews, 2006). Moreover, to date and to our knowledge, no critical reviews have been done regarding distance functions in organic farming systems performance analysis.

Accordingly, this study aims to discuss the distance functions comprehensively. The objectives of this study are to (i) introduce the different distance function methods available in the literature, (ii) identify the distance function methods and estimation methods used in organic farming systems performance analysis, and (iii) make a discussion on these distance functions, and find research gaps.

MATERIALS AND METHODS

The study material is constituted of scientific articles, and the methodology adopted is that performed by Lokonon *et al.* (2019). The documents were identified using keyword searching by utilising search terms such as "distance function methods", "efficiency analysis" and "organic farming" using web search engines (Publish or Perish, Google scholar, web of science and Scopus) and additional references from retrieved articles. The main inclusion criteria used for research papers was the scope of papers and books (focused on distance functions in organic farming efficiency analysis) published from 2010 to 2020. The outcomes of the search queries were initially examined to determine their relevance by reading their titles and abstracts, after which full texts were downloaded for further scrutiny. The content of these retrieved articles was then carefully examined to re-select the most important ones. Commentaries, purely descriptive studies, and letters were excluded. After that, 20 papers were identified in this literature review. The research papers considered enabled us to describe distance functions. In addition, the content of these research papers helped us identify and discuss distance function methods used in organic farming performance analysis. Tables and figures were mainly used to present outcomes from the selected papers.

RESULTS AND DISCUSSION

Overview of papers selected: The number of selected papers that used distance functions in organic farming efficiency assessment over the past ten years is shown in figure 1. The figure indicated that most articles were published from 2012 to 2016 and in 2018. Moreover, most of the selected papers were from journals such as *Sustainability journal* (10.53%), *Journal of Productivity Analysis* (10.53%), *Ecological Economics* (10.53%), and *Journal of Agricultural and Applied Economics* (10.53%). Very few articles were selected from journals such as *German Journal of Agricultural Economics*, *Environmental and Resource Economics*, *Agricultural and Food Science*, *International Journal of Economics and Finance*, *Land Use Policy*, *American Journal of Agricultural Economics*, *Review of Agricultural and Applied Economics*, *European Review of Agricultural Economics*, *International Journal of Economics and Statistics* and *Review of Agricultural and Environmental Studies*.

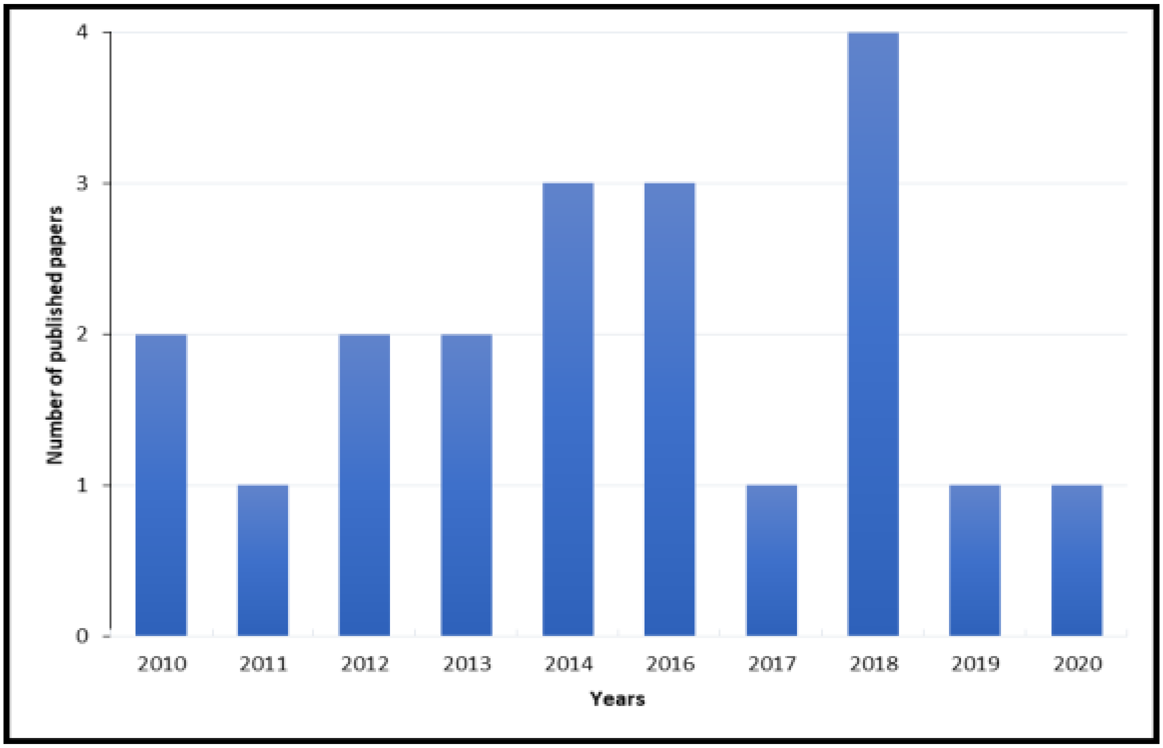

Figure 1: Number of selected papers on distance functions in organic farming efficiency assessment per year of publication.

Distance function methods: Shephard (1953, 1970) first introduced the notion of the distance function. Shephard (1970) has stated that if a farmer produces more than one output using many inputs, distance functions may be used to characterize the production technology. Several previous studies have documented the concept and properties of the distance functions (Färe, 1988; Färe and Primont, 1995; Kumbhakar and Lovell, 2000; Coelli *et al.,* 2005). Several distance functions are distinguished in the literature, and the commonly used are (i) *input distance function*, (ii) *output distance function* and (iii) *directional and hyperbolic distance functions*. However, the choice depends on the direction/focus of the study, in particular, the objective of the producers, exogeneity assumptions, data availability and the complexity of the estimation procedures (Daidone and D'Amico, 2009). The main advantage of the distance functions is that none of the conventional distance functions (input distance function or output distance function) requires any behavioural assumptions (i.e. cost minimization, revenue maximization, and profit maximization) (Kumbhakar and Lovell, 2000; Coelli *et al.,* 2005).

1 Input distance function (IDF): Following Alene *et al.* (2006), the input distance function looks at the amount to which the inputs may be proportionally reduced to produce a fixed output. The input distance function, introduced by Shephard (1970), may be defined on the input set $V(y)$ as:

$$D_I(x,y) = \max\{\rho : (x/\rho) \in V(y)\}, \quad (1)$$

where the input set $V(y)$represents the set of all input vectors, $1/\rho$ represents the proportional contraction of inputs that are required to reach the inner boundary of the input set or the production frontier holding the outputs constant, $x \in R_+^N$, which can produce the output vector, $y \in R_+^M$. That is,

$$V(y) = \{x \in R_+^N : x\ can\ produce\ y\} \quad (2)$$

$D_I(x,y)$ requires to be linearly homogenous of degree one in x ($D_I(\lambda x,y) = \lambda D_I(x,y)$) and satisfies the economic regularity conditions of monotonicity and concavity. In addition, following Alene *et al.* (2006), the input distance function, $D_I(x,y)$, will take a value which is greater than or equal to unity if the input vector, x, is an element of the feasible input set, $V(y)$, that is, $D_I(x,y) \geq 1$ if $x \in V(y)$ or will take a value of unity if x is located on the inner boundary of the input requirement set, $V(y)$.

2 Output distance function (ODF): Following Alene *et al.* (2006), the output distance function looks at the maximum expansion of the output vector with a given set of fixed input vectors. The output distance function, introduced by Shephard (1970), is defined on the output set, as:

$$D_o(x,y) = \min\{\theta : (y/\theta) \epsilon V(x)\} \quad (3)$$

where $V(x)$, represents the set of all output vectors, $1/\theta$ represents the proportional expansion of outputs that are required to reach the upper boundary of the output set or the production frontier holding the inputs fixed, $y \in R_+^M$, which can be produced using the input vector, $x \in R_+^K$. That is,

$$V(x) = \{y \in R_+^M : x\ can\ produce\ y\} \quad (4)$$

As noted in Lovell *et al.* (1994), $D_o(x,y)$ is assumed non-decreasing, positively linearly homogeneous and convex in y, and non-increasing and quasi-convex in x (Coelli *et al.*, 1998). Moreover, following Alene *et al.* (2006), the output distance function,$D_o(x,y)$, will take a value which is less than or equal to one if the output vector, y, is an element of the feasible production set, $V(x)$, that is, $D_o(x,y) \leq 1$ if $y \in V(x)$. Furthermore, the output distance function will take a value of unity if y is located on the outer boundary of the production possibility set, that is, $D_o(x,y) = 1$ if $y \in Isoq\ V(x) = \{y : y \in V(x),\ wy \notin V(x),\ w > 1\}$, using similar notation to that used by Lovell *et al.*, (1994) (Alene *et al.*, 2006).

3 Directional distance function (DDF): The directional distance function (DDF) was suggested by Chambers *et al.* (1996) and used by Luenberger (1992) and Chung *et al.* (1997) to examine environmental efficiency and productivity. According to the authors, this method emerged as an alternative to Shephard's radial distance functions to treat desirable and undesirable outputs simultaneously and asymmetrically in a specified direction (see, for instance, Färe *et al.*, 1994; Scheel, 2001; Feng and Serletis, 2009). It allows simultaneous contraction of inputs (and undesirable outputs) and expansion of desirable outputs in an explicit direction vector (Muna, 2018). It offers the advantage that it simultaneously takes into account intended and unintended outputs and can be estimated using the same linear programming techniques employed for Data Envelopment Analysis (DEA) (Falavigna *et al.*, 2014). However, its weakness is that we choose the directional vector arbitrarily.

We denote the inputs by $x = (x_1, \dots x_N) \in R_+^N$, the desirable outputs by $y = (y_1, \dots y_M) \in R_+^M$ and the undesirable outputs by $b = (b_1, \dots b_J) \in R_+^J$. The output represents the technology sets$P(x)$, $x \in R_+^N$ where:

$$P(x) = \{(y,b) : x\ can\ produce\ (y,b)\} \quad (5)$$

Apart from the standard assumptions of convex, compact and freely disposable inputs, the following additional assumptions are imposed on the output set (see, Molinos-Senante *et al.*, 2015):

First, it is assumed that the undesirable outputs and desirable outputs satisfy null-jointness assumption, i.e., if $(y, b) \in P(x)$ and b = 0, then y = 0. In other words, if a (y, b) combination is feasible and no undesirable output is produced, then no desirable output is produced (Chung *et al.*, 1997).
Second, it is assumed that the undesirable outputs and the desirable outputs satisfy joint weak disposability, i.e., if $(y, b) \in P(x)$ and $0 \leq \theta \leq 1$ then, $(\theta y, \theta b) \in P(x)$. This assumption implies that any reduction of undesirable outputs involves a cost (Chung *et al.*, 1997).
Third, it is assumed that the desirable outputs satisfy strong or free disposability. This means that it is possible to reduce the desirable outputs without reducing the undesirable outputs. Formally, if $(y, b) \in P(x)$, then for $y' \leq y$, $(y', b) \in P(x)$ (Chung *et al.*, 1997).
Taken into account the above assumptions, the DDF is defined as follows:

$$\vec{D}(x, y, b, g) = max\{\beta: (x - \beta g_x, y + \beta g_y, b - \beta g_b) \epsilon P(x)\} \quad (6)$$

where $g = (-g_x, g_y, -g_b)$ is a non-zero directional vector and is always positive $(g > 0)$; β (≥ 0) is the inefficiency score. A proportion β seeks to increase the desirable output and reduce the undesirable output.
The directional output distance function (DODF) is obtained by setting $g_x = 0$ and gives the maximum feasible proportional contraction in bad outputs and expansion in good outputs along a pre-assigned direction $g = (-g_x = 0, g_y = y, -g_b = -b)$ as follows (Chung *et al.*, 1997):

$$\overrightarrow{D_o}(x, y, b, 0, g_y, -g_b) = max\{\beta: (x, y + \beta g_y, b - g_b) \in P(x)\} \quad (7)$$

By setting $g_y = 0$ and $g_b = 0$, we get the directional input distance function (DIDF) which allows only for input contraction holding outputs fixed as follows (Muna, 2018):

$$\overrightarrow{D_I}(x, y, b, -g_x, 0, 0) = max\{\beta: (x - \beta g_x, y, b) \in P(x)\} \quad (8)$$

4 Hyperbolic distance function (HDF): The hyperbolic distance function was introduced by Färe *et al.* (1985, 1989) and is defined as the maximum expansion and equiproportionate contraction respectively for the desirable output vector and the undesirable output vector that places a producer on the boundary of the technology (Färe *et al*., 1989; Cuesta *et al.*, 2009). The hyperbolic distance function $D_H: R_+^N \text{x } R_+^M \text{ x } R_+^J \rightarrow R_+ U\{+\infty\}$ is defined by:

$$D_H(x, y, b) = \inf\{\theta > 0 : (x, y/\theta, b\theta \in P(x)\} \quad (9)$$

The HDF inherits its name from the hyperbolic path that it follows toward the production frontier. As DDF, it has the virtue of treating desirable and undesirable outputs asymmetrically, thus providing an environmentally friendly characterization of the production technology (Wang *et al.*, 2017). As noted in Adenuga *et al.* (2019), although the goals of the directional and hyperbolic distance function are similar, they differ from their homogeneity property (i.e., multiplicative homogeneity property for hyperbolic distance function and translation property for directional distance function). The range of the HDF is $0 < D_H(x, y, b) \leq 1$. If the technology satisfies the customary axioms, then the HDF satisfies the following properties (Cuesta *et al.*, 2009):

(i) It is almost homogeneous, i.e., $D_H(\theta^{-1}x, \theta y, \theta^{-1}b) = \theta D_H(x, y, b)$, $\theta > 0$,
(ii) Non-decreasing in desirable outputs, $D_H(x, \lambda y, b) \leq D_H(x, y, b)$, $\lambda \in [0,1]$,
(iii) Non-increasing in undesirable outputs, $D_H(x, y, \lambda b) \leq D_H(x, y, b)$, $\lambda \geq 1$,
(iv) Non-increasing in inputs, $D_H(\lambda x, y, b) \leq D_H(x, y, b)$, $\lambda \geq 1$.

Distance functions in organic farming efficiency assessment : From the papers selected, only twenty targeted organic farming (e.g. Park and Lohr, 2010; Areal *et al.,* 2012; Mamardashvili, 2013; Cechura *et al.,* 2014; Mamardashvili *et al.,* 2014; Manevska-Tasevska *et al.,* 2014; Lien *et al.,* 2016; Anik *et al.,* 2017; Lakner *et al.,* 2018; Adenuga *et al.,* 2019; Le *et al.,* 2020.). Most studies (80%) used distance functions methods to assess efficiency well as 20% assessed the productivity (total factor productivity). Regarding the efficiency assessment, 65% of the studies estimated the so-called technical efficiency (e.g., Park and Lohr, 2010; Areal *et al.,* 2012; Mamardashvili, 2013; Mamardashvili *et al.,* 2014; Manevska-Tasevska *et al.,* 2014; Lakner *et al.,* 2018; Le *et al.,* 2020.) while 25% estimated environmental efficiency (e.g. Mamardashvili, 2013; Agostino, 2016; Huang *et al.,* 2016; Adenuga *et al.,* 2019; etc.). The remaining studies focused on allocative efficiency and scale efficiency (e.g. Park and Lohr, 2010; Rasmussen, 2010; Serra *et al.,* 2011). These results suggest that studies using distance functions in organic farming performance analysis targeted mostly technical efficiency and environmental efficiency. These results re-join works of Riaz (2016) who suggested that the major focus in various agricultural studies is on technical efficiency. For Lansink *et al.* (2002), environmental efficiency is an appropriate representation of farm efficiency since the protection of the environment is one of the objectives of organic farming. According to Mardani *et al.* (2017), environmental aspect has become an important problem related with economic and social sustainable development and usually people recognize the significant of environmental efficiency assessment because it can offer public policy makers and designers with some quantitative information for evaluation, public communication and policy analysis. With respect to distance functions methods, the results showed that most of the articles (40%) used output distance function, 25% used directional distance function (with a predominance of directional output-oriented distance function), 20% used input distance function and 15% used hyperbolic distance function. Then, when we combined the performance measure with the distance method (figure 2), we noticed that the use of distance function methods depends on the orientation of each study. These results re-join that of Daidone and D'Amico (2009) according to which, the choice of these methods depend on the direction/focus of the study in particular, the objective of the producers, exogeneity assumptions, data availability and the complexity of the estimation procedures. For instance, Areal *et al.* (2012) employed output distance function to assess technical efficiency of dairy farms by incorporating provision of environmental goods as one of the outputs of the farms and found that incorporation of provision of environmental goods as outputs impact farm efficiency rankings, which may have important political implications. Similarly, Le *et al.* (2020) used hyperbolic distance function to assess the impact of Greenhouse gas (GHG) reduction on the technical efficiency of Alberta's dairy farms and found that environmentally adjusted technical efficiency and technical efficiency estimates are highly correlated; thus, reducing GHG emissions may not result into decreased efficiency. The figure indicated that the output distance function is most used to estimate technical efficiency and productivity whereas the directional distance function is most used to assess the environmental efficiency or both (technical efficiency and environmental efficiency). These results suggested on the one hand that the output distance is well suited to evaluate technical efficiency and productivity of organic farming in the sense that according to Alene *et al.* (2006), this approach looks at the maximum expansion of the output vector with a given set of fixed input vector; which meets to requirements of most of the organic farmers who seek to expand their output using given inputs. This justifies the choice of output distance function in most of selected articles comparatively to input distance function for efficiency analysis (e.g. Park and Lohr, 2010; Areal *et al.,* 2012; Machek and Špička, 2013; Mamardashvili, 2013; Cechura *et al.,* 2014; Mamardashvili *et al.,* 2014; Anik *et al.,* 2017; Lakner *et al.,* 2018). On the other hand, these results also suggested that directional distance function in particular directional output distance function is well suited for environmental efficiency or when one of the environmental indicator is incorporated as output (e.g. Agostino, 2016; Schulte *et al.,* 2018). Results from this study confirmed the findings of Cuesta *et al.* (2009) who indicated that the directional distance function is well suited for environmental performance analysis contrary to conventional distance functions which aim to expand all outputs (desirable outputs and undesirable outputs) or contract all inputs equiproportionately. Results of Zhang and Choi (2014) also supported Cuesta *et al.* (2009) by showing that if one wishes to focus on environmental technical efficiency, the radial directional distance function may be used. Moreover, from the selected articles, two estimation methods of distance functions were identified namely parametric (SFA) and non-parametric methods (DEA). Results indicated that SFA was used in fourteen studies while DEA was used in six studies. Findings from this study have further shown that although both estimation methods are appropriate to estimate distance functions, parametric approach takes precedence over non-parametric approach. This result confirms for instance the choice of parametric approach by Adhikari and Bjorndal (2012) in their study. According to Adhikari and Bjorndal (2012), SFA is more preferred to DEA because it takes into account noise term, which is related to variability in production due to random factors such as resource availability, missing variables, environmental influences, weather and measurement errors. The most common estimation technique used in stochastic frontier approach is the maximum likelihood estimation which requires a distribution for the technical inefficiency as well as the random error in order to disentangle one from the other (e.g. Park and Lohr, 2010; Mamardashvili, 2013; Mamardashvili *et al.,* 2014; Adenuga *et al.,* 2019; Le *et al.,* 2020). Moreover, in a number of efficiency studies, 62.2% of the studies used panel data while 37.8% used cross sectional data sets to evaluate the change in efficiency over time. With respect to type of farming system, ten studies dealt with dairy farms (e.g. Rasmussen, 2010; Serra *et al.,* 2011; Areal *et al.,* 2012; Jan *et al.,* 2012; Mamardashvili, 2013; Mamardashvili *et al.,* 2014; Lien *et al.,* 2016; Schulte *et al.,* 2018; Adenuga *et al.,* 2019; Le *et al.,* 2020) contrary to other farming systems (cocoa, grassland, citrus, arable).

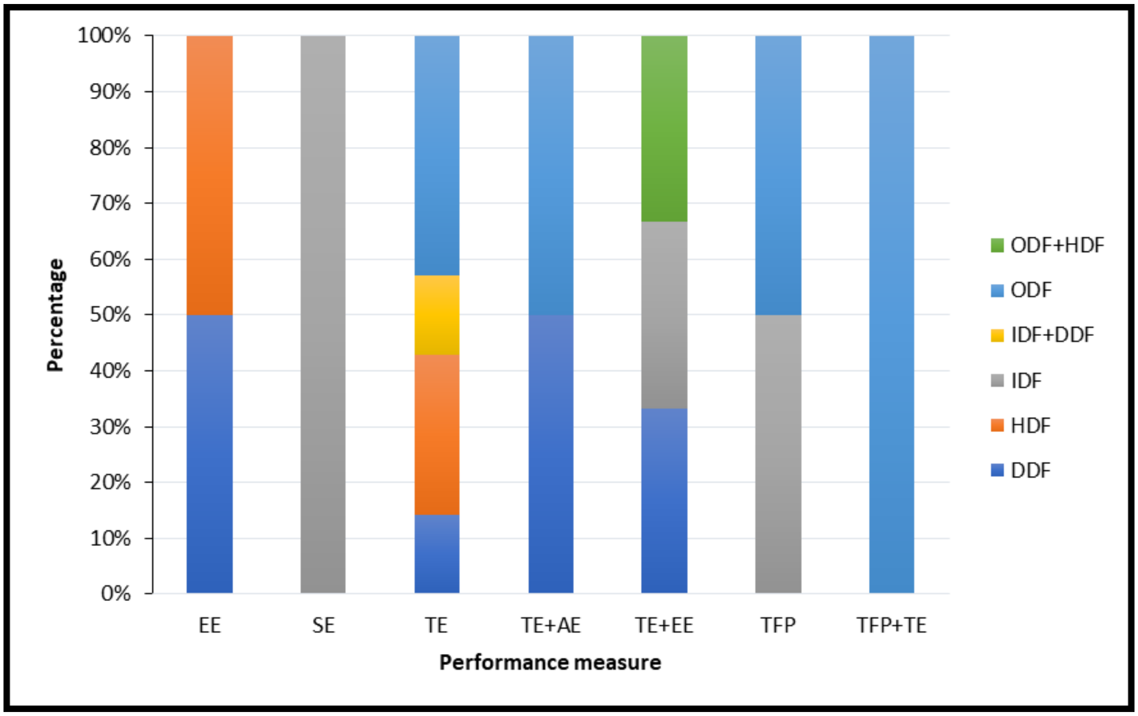

Figure 2: Share of distance function methods in performance measure.
Legend: EE=Environmental Efficiency, SE=Scale Efficiency, TE= Technical Efficiency, AE=Allocative Efficiency, TFP= Total Factor Productivity.

CONCLUSION

This study made a critical review of literature on distance function approaches in organic farming efficiency analysis. The study showed that, although the applications involving distance functions have increased in recent years, the uses of distance functions in organic farming efficiency analysis are very few. Therefore, future studies should focus on organic farming systems in general and in particular organic cotton to contribute to the literature on distance function approaches. By exploring the performance of organic cotton farming units, researchers might better understand the implications of distance function comes in organic farming efficiency analysis. Secondly, according to selected articles, there are several distance function methods, and some of the mainly used methods include output distance function and directional output distance function. The choice of these methods depends on the orientation of the study. This indicates that distance functions are powerful tools for assessing organic farming efficiency. Future research should evaluate the performance of these distance function methods under varying conditions to further light on the method's strengths and weaknesses and help researchers make an appropriate choice. Thirdly, parametric and non-parametric approaches are the most used concerning estimation methods of distance functions. This particular paper has a limitation, which can present opportunities and recommendations for future studies. One of the limitations of this study is that the number of identified articles was not high, despite the time duration considered. One possible explanation for this number of articles used could be that since the development of distance functions, there were not many studies based on distance functions. It was only in recent years that they have been the subject of many studies.

ACKNOWLEDGEMENT

This research was supported by African Excellence Center in Mathematical Sciences, Informatics and Applications (CEA-SMIA) of Institute of Mathematics and Physical Sciences. Authors acknowledge this institution and its donors.

REFERENCES

Abdulai A and Tietje H, 2007. Estimating technical efficiency under unobserved heterogeneity with stochastic frontier models: application to northern German dairy farms. European Review of Agricultural Economics 34(3):393-416.

Adenuga AH, Davis J, Hutchinson G, Donnellan T and Patton M, 2019. Environmental efficiency and pollution costs of nitrogen surplus in dairy farms: a parametric hyperbolic technology distance function approach. Environmental and Resource Economics. Https: //doi.org/10.1007/s10640-019-00367-2.

Adhikari CB and Bjorndal T, 2012. Analyses of technical efficiency using SDF and DEA models: evidence from Nepalese agriculture. Applied Economics 44(25):3297-3308, http ://dx.doi.org/10.1080/00036846.2011.572856.

Agostino M, 2016. Organic Agriculture, Greenhouse Gas Emissions and Environmental Efficiency: An Empirical Study on OECD Countries. International Journal of Economics and Finance 8(11):78-95.

Alene AD, Manyong VM and Gockowski J, 2006. The production efficiency of intercropping annual and perennial crops in southern Ethiopia: A comparison of distance functions and production frontier. Agricultural Systems 91:51-70.

Anik AR, Rahman S and Sarker JR, 2017. Agricultural productivity growth and the role of capital in South Asia (1980{2013). Sustainability 9(470):1-24.

Areal FJ, Tiffin R and Balcombe KG, 2012. Provision of environmental output within a multi-output distance function approach. Ecological Economics, Elsevier 78:47-54.

Beltran-Esteve M and Reig-Martinez E, 2014. Comparing conventional and organic citrus grower efficiency in Spain. Agricultural Systems 129:115-123.

Beltran-Esteve M, Reig-Martinez E and Estruch-Guitart V, 2017. Assessing eco-efficiency: A metafrontier directional distance function approach using life cycle analysis. Environmental Impact Assessment Review 63:116-127.

Blancard S and Martin E, 2013. Energy efficiency measurement in agriculture with imprecise energy content information. Energy Policy, http: //dx.doi.org/10.1016/j.enpol.2013.10.071.

Bonou-zin RDC, Allali K and Fadlaoui A, 2019. Environmental Efficiency of Organic and Conventional Cotton in Benin. Sustainability 11(3044):1-17, Doi: 10.3390/su11113044.

Brümmer B, Glauben T and Lu WC, 2006. Policy reform and productivity change in Chinese agriculture: A distance function approach. Journal of Development Economics 8:28-31, http://doi.org/10.1016/j.jdeveco.2005.04.009.

Brümmer B, Glauben T and Thijssen G, 2002. Decomposition of productivity growth using distance functions: The case of dairy farms in three European countries. American Journal of Agricultural Economics 84:628-44.

Cechura L, Hockmann H, Mala Z and Maly M, 2014. Productivity and efficiency differences between Czech and Slovak milk producers. Review of Agricultural and Applied Economics 2:17-21.

Chambers RG, Chung Y and Färe R, 1996. Benefit and Distance Functions. Journal of Economic Theory 70:407-419.

Chung YH, Färe R and Grosskopf S, 1997. Productivity and Undesirable Outputs: A Directional distance function approach. Journal of Environmental Management 51:229-240.

Clemente F, Lirio VS and Gomes MFM, 2015. Technical efficiency in Brazilian citrus production. Bio-based and Applied Economics 4(2):165-178.

Coelli TJ and Perelman S, 1999. A comparison of parametric and non-parametric distance functions: With application to European railways. European Journal of Operational Research 117:326-339.

Coelli TJ, Prasada RDS and Battese GE, 1998. An Introduction to Efficiency and Productivity Analysis. Kluwer Academic Publishers Boston USA.

Coelli TJ, Prasada RDS and Battese GE, 2005. An introduction to efficiency and productivity analysis. 2nd edition, Norwell: Kluwer Academic Publishers.

Cuesta RA, Lovell CAK and Zofio JL, 2009. Environmental efficiency measurement with translog distance functions: A parametric approach. Ecological Economics 68:2232-2242.

Daidone S and D'Amico F, 2009. Technical efficiency, specialization and ownership form: evidences from a pooling of Italian hospitals. Journal of Productivity Analysis 32:203-216.

Falavigna G, Ippoliti R, Manello A and Ramello GB, 2014. Judicial productivity, delay and efficiency: A Directional distance function (DDF) approach. European Journal of Operational Research, http ://dx.doi.org/10.1016/j.ejor.2014.07.014.

Färe R, 1988. Fundamentals of production theory, Lecture Notes in Economics and Mathematical Systems Heidelberg: Springer-Verlag.

Färe R and Primont D, 1990. A distance function approach to multioutput technologies. Southern Economic Journal 56(4):879-91, http ://www.jstor.org/stable/1059878 Accessed 15 October 2015.

Färe R and Primont D, 1995. Multi-output Production and Duality: Theory and Applications. Kluwer Academic Publishers Boston.

Färe R, Grosskopf S and Lovell CAK, 1985. The Measurement of Efficiency of Production. Kluwer Academic publishers Boston.

Färe R, Grosskopf S, Lovell CAK and Pasurka C, 1989. Multilateral productivity comparisons when some outputs are undesirable: A nonparametric approach. The Review of Economics and Statistics 71:90-98.

Färe R, Grosskopf S, Lovell CAK and Yaisawarng S, 1993. Derivation of Shadow Prices for undesirable outputs: A Distance Function Approach. The Review of Economics and Statistics 75(2):374-380.

Färe R, Grosskopf S, Norris M and Zhang Z, 1994. Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries. American Economic Review 84(1):66-83.

Feng G and Serletis A, 2009. Efficiency and productivity of the US. banking industry, 1998-2005: evidence from the Fourier cost function satisfying global regularity conditions. Journal of Applied Econometrics 24:105-138.

Franksen T and Latacz-Lohmann U, 2006. Beurteilung der technischen Effizienz der Agrarsektoren der EU-Beitrittsländer anhand parametrischer und nichtparametrischer Analyseverfahren. Agrarwirtschaft 55(7):323-333.

Franksen T, Gü nther G and Latacz-Lohmann U, 2007. Empirische Untersuchungen zum optimalen Spezialisierungsgrad ökologisch wirtschaftender Marktfruchtbetriebe. Agrarwirtschaft 56(4):187-200.

Grosskopf S, Hayes K, Taylor L and Weber W, 1997. Budget constrained frontier measures of fiscal equality and efficiency in schooling. Review of Economics and Statistics 79:116-124.

Huang W, Bruemmer B and Huntsinger L, 2016. Incorporating measures of grassland productivity into efficiency estimates for livestock grazing on the Qinghai-Tibetan Plateau in China. Ecological Economics, Elsevier 122:1-11.

Jan P, Lips M and Dumondel M, 2012. Total factor productivity change of Swiss dairy farms in the mountain region in the period 1999 to 2008. Review of Agricultural and Environmental Studies 93(3):273-298.

Kalirajan KP and Shand RT, 1999. Frontier Production functions and technical efficiency measures. Journal of Economic Survey 13(2):149-170.

Kamdem CB, 2012. The determinants of marketing efficiency of cocoa farmer organization in Cameroon. International Business Research 5(9):158-170.

Kellermann M and Salhofer K, 2011. Der Zusammenhang zwischen technischer Effizienz und wirtschaftlichem Erfolg: eine Analyse für bayerische Milchviehbetriebe. German Journal of Agricultural Economics 60(4):230-242.

Kumbhakar S and Lovell CAK, 2000. Stochastic frontier analysis. Cambridge United Kingdom: Cambridge University Press. 333p.

Lakner S and Breustedt G, 2017. Efficiency Analysis of Organic Farming Systems A Review of Concepts, Topics, Results and Conclusions. German Journal of Agricultural Economics 66:85-108.

Lakner S, Kirchweger S, Hoop D, Brümmer B and Kantelhardt J, 2018. The effects of diversification activities on the technical efficiency of organic farms in Switzerland, Austria, and Southern Germany. Sustainability 10(1304):1-18.

Lansink AO, Pietola KS and Bäckman S, 2002. Efficiency and productivity of conventional and organic farms in Finland 1994-1997. European Review of Agricultural Economics 29(1):51-65.

Le S, Jeffrey S and An H, 2020. Greenhouse Gas Emissions and Technical Efficiency in Alberta Dairy Production: What Are the Trade-Offs? Journal of Agricultural and Applied Economics 52:177-193.

Lien G, Kumbhakar SC and Hardaker JB, 2016. Accounting for risk in productivity analysis: an application to Norwegian dairy farming. Journal of Productivity Analysis, Doi 10.1007/s11123-016-0482-2.

Lohr L and Park T, 2010. Local Selling Decisions and the Technical Efficiency of Organic Farms. Sustainability 2:189-203, Doi: 10.3390/su2010189.

Lokonon BE, Mba RB, Gbeha M and Glèlè Kakaï R, 2019. Parameters Estimation Methods in Generalized Linear Mixed Models (GLMMs) Applied in Ecology: A Critical Review. International

Journal of Engineering and Future Technology 16(3)10-27.

Lovell CAK, Richardson S, Travers P and Wood L, 1994. Resources and functionings: a new view of inequality in Australia. In: Eichhorn W (ed.) Models and Measurement of Welfare and Inequality; Springer-Verlag Berlin p787-807.

Luenberger DG, 1992. Benefit functions and duality. Journal of Mathematical Economics 21:461-486.

Machek O and Špička J, 2013. Measuring performance growth of agricultural sector: a total factor productivity approach. International Journal of Economics and Statistics 1:200-208.

Mamardashvili P, 2013. Measuring economic and environmental performance of Swiss dairy farms using stochastic frontier analysis. Research-collection.ethz.ch.

Mamardashvili P, Bokusheva R and Schmid D, 2014. Heterogeneous farm output and technical efficiency estimates. German Journal of Agricultural Economics 1:16-30, ageconsearch.umn.edu.

Manevska-Tasevska G, Hansson H and Rabinowicz E, 2014. Input saving possibilities and practices contributing to more efficient beef production in Sweden. Agricultural and Food Science 23:118-134.

Mardani A, Zavadskas EK, Streimikiene D, Jusoh A and Khoshnoudi M, 2017. A comprehensive review of data envelopment analysis (DEA) approach in energy efficiency. Renewable and Sustainable Energy Reviews 70:1298-1322.

Mensah A and Brümmer B, 2016. A multi-output production efficiency analysis of commercial banana farms in the Volta region of Ghana: A stochastic distance function approach. African Journal of Agricultural and Resource Economics 11(4):305-316.

Molinos-Senante M, Hanley N and Sala-Garrido R, 2015. Measuring the CO2 shadow price for wastewater treatment: A directional distance function approach. Applied Energy 144:241-249.

Muna E, 2018. Essays on Distance Functions and Inefficiency Measurement. Ph.D Thesis, University of Calgary, Calgary, AB. Doi: 10.11575/PRISM/32405, http ://hdl.handle.net/1880/107194. 218p.

Newman C and Matthews A, 2006. The productivity performance of Irish dairy farms 1984-2000: A multiple output distance function approach. Journal of Productivity Analysis 26:191-205.

Park TA and Lohr L, 2010. Assessing the technical and allocative efficiency of US organic producers. Journal of Agricultural and Applied Economics 2:247-259.

Rasmussen S, 2010. Scale efficiency in Danish agriculture: an input distance-function approach. European Review of Agricultural Economics 37(3):335-367.

Riaz AC, 2016. Efficiency of small scake farmers in Pakistan's Punjab and the role of extension services in its improvement. Ph.D. Thesis, University of Reading. 341p.

Scheel H, 2001. Undesirable outputs in efficiency valuations. European Journal of Operational Research 132(2):400-410.

Schulte HD, Armbrecht L, Bürger R, Gauly M, Musshoff O and Hüttel S, 2018. Let the cowsgraze: An empirical investigation on the trade-off between efficiency and farm animal welfare in milk production. Land use policy, Elsevier 79:375-385.

Serra T, Lansink AO and Stefanou SE, 2011. Measurement of dynamic efficiency: A directional distance function parametric approach. American Journal of Agricultural Economics 93(3):756-767.

Shephard RW, 1953. Cost and production functions. Princeton, NJ: Princeton University Press. 104p.

Shephard RW, 1970. Theory of Cost and Production functions. Princeton NJ: Princeton University Press. 308p.

Singbo AG, Lansink AO and Emvalomatis G, 2014. Estimating farmer's productive and marketing inefficiency: an application to vegetable producers in Benin. Journal of Productivity Analysis, Doi 10.1007/s11123-014-0391-1.

Singbo AG, Lansink AO and Emvalomatis G, 2015. Estimating shadow prices and efficiency analysis of productive inputs and pesticide use of vegetable production. European Journal of Operational Research 245:265-272.

Stolze M, Piorr A, Häring A and Dabbert S, 2000. The Environmental Impacts of Organic Farming in Europe, In: Organic farming in Europe. Economics and Policy, Hohenheim, Stuttgart 6:1437-6512.

Tiedemann T and Latacz-Lohmann U, 2011. Empirische Analysen zur Produktivitäts-entwicklung im ökologischen und konventionellen Landbau. German Journal of Agricultural Economics 60(2):101-118.

Wang K, Che L, Ma C and Wei Y, 2017. The shadow price of CO2 emissions in China's iron and steel industry. Sci Total Environ 598:273-281, 2017.

Zhang N and Choi Y, 2014. A note on the evolution of directional distance function and its development in energy and environmental studies 1997-2013. Renewable and Sustainable Energy Reviews 33:50-59.

Zhang Y and Brümmer B, 2011. Productivity change and the effects of policy reform in China's agriculture since 1979. Asian-Pacific Economic Literature 25:131-50.