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Measuring Energy efficiency in public enterprise: The case of Agribusiness

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Abstract

Public sector enterprises claim to be more socially conscious than their counterparts in the private sector. Often it is touted as the main justification for their existence. Public sector has taken a lead in enhancing energy efficiency not just for profitability but also for environmental concerns. Measurement of energy efficiency, however, presents a plethora of challenges. Adding on of social concerns to environmental challenges has widened the scope of sustainability beyond a buzzword. Recent advances in Data envelopment analysis show how measurement can be done reliably.

KEYWORDS: Energy efficiency, sustainability, technical efficiency, allocative efficiency

Introduction

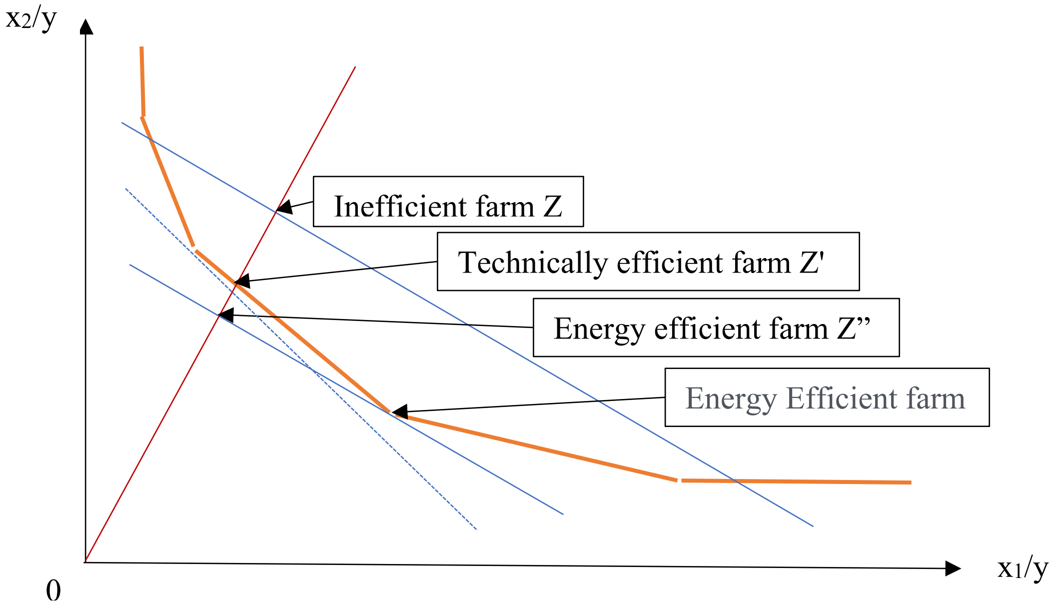
Agriculture is one of the few industries that creates resources repetitively from nature in a sustainable way by creating organic matter and its derivatives by utilizing solar energy and other materials in nature. Agribusiness is an energy consuming sector and it is also an energy producer through bioenergy. Modern agribusiness applies scientific principles for the optimal conversion of natural resources into agricultural land, machinery, structure, processes, and systems for increasing productivity. Increases in crop productivity achieved 1960s onwards in Latin America are attributable to advances in sciences and the significant use of fossil fuel-powered farm equipment and machinery, intensive tillage, irrigation and chemical inputs. Between 1980 and 2012, regional agricultural output per worker increased by 82 per cent and total factor productivity increased by 45 percent (Nin Pratt et al., 2015). This improved performance of agriculture was the result of fast growth in the use of fertilizer, increases in land productivity, and growth in the use of capital that expanded cultivated area per worker (Martin-Retortillo et al., 2022). As agriculture transforms itself from a subsistence activity to agribusiness in Latin America, it has become increasingly reliant on chemical fertilizers derived from fossil fuels, natural gas and diesel-powered machinery. Storage, processing and distribution of agricultural produce are also often energy-intensive activities (Moreno-Moreno et al., 2018). There is significant uncertainty concerning the price and availability of energy needed to power farm operations and produce key inputs, like irrigation and fertilizers. This uncertainty jeopardizes future productive potential and reduces productivity of inputs. Higher energy costs, therefore, have a direct and strong impact on profitability in agribusiness. High-input, energy-intensive agriculture has been called a product of knowledge applied before giving consideration to its full ecological and social costs (Orr, 1996). While the importance of energy efficiency in the sector is being increasingly examined, economic and cultural barriers in Latin American societies hinder the full application of energy enforcement standards and a lack of human resources (caused by budgetary constraints) means that monitoring and enforcement systems are inefficient (ECLAC, 2014). Availability and quality of data is a major constraint [IEA]. Decision makers are generally hesitant to act in the absence of accurate data. This paper seeks to propose a way to measure energy efficiency in agriculture in a cost framework in presence of uncertainty.

Technical efficiency and allocative efficiency

The terms "energy conservation" and "energy efficiency" are often used interchangeably, but are different. Energy conservation means using less energy and is usually a human behavioural change; energy efficiency, means using energy more effectively, and is mainly a technological change. Energy efficiency is commonly denoted as outputs and inputs converted to energy. The most basic definition of energy efficiency derives from the first-law of thermodynamics and measures the ratio of ‘useful’ energy outputs to the heat content, or calorific value of fuel inputs (Berndt, 1978). Overall productive efficiency is commonly defined as a product of technical efficiency and allocative efficiency (Farell, 1957). The allocative efficiency measures a producer’s success in choosing an optimal set of inputs with a given set of energy contents in inputs; this is distinguished from the technical efficiency concept associated with the production frontier, which measures success in producing maximum output from a given set of inputs. Not all farmers can utilise the minimum inputs required to produce the outputs they choose to produce, given the technology at their disposal. In light of the evident failure of at least some producers to optimize, it is desirable to recast the analysis of production away from the traditional production function approach toward a frontier based approach. Hence we are concerned with the estimation of frontiers, which envelop data, rather than with functions, which intersect data (Daraio & Simmer, 2007). For measuring and decomposing energy efficiency, we use linear programming to construct a non-parametric frontier.

In figure 1 segmented orange line is the technically efficient frontier when there is one input (y) and two inputs x_1 and x_2. On the radial line, 0Z'/0Z gives the technical efficiency of farm Z. If the energy content of inputs x_1 and x_2 are known we can draw iso-energy lines which are in blue. The lowest iso-energy line touching the technically efficient frontier is relevant for our purpose of energy efficiency. Z' in figure 1 is technically efficient but not allocatively efficient. We derive the relationship 0Z"/0Z = (0Z'/0Z) X (0Z"/0Z').

Figure 1: Measurement of technical efficiency and allocative efficiency



The measurement of energy efficiency requires assessment of direct and indirect energy content of each input which is a contentious issue. The most common technique of measurement is Life Cycle Energy Assessment (LCEA) which was earlier called energy analysis (Hammond, 2004). In this method all energy inputs to a product are accounted for - direct energy inputs during manufacture as also all energy inputs needed to produce components, materials and services needed for the manufacturing process. A problem this method cannot resolve is that different energy forms have different quality and value even in natural sciences, as a consequence of the two main laws of thermodynamics. According to the first law of thermodynamics, all energy inputs should be accounted with equal weight, whereas by the second law diverse energy forms should be accounted by different values. With LCEA, the total life cycle energy input is established by ignoring value difference between energy inputs or assigning an arbitrary value ratio (e.g., a joule of electricity is 2.6 times more valuable than a joule of heat or fuel input). Rigid system boundaries make accounting for changes in the system difficult. This is sometimes referred to as the boundary critique to systems thinking. Data from generic processes may be based on averages; whereas in case of many products the manufacturers refuse to give complete information claiming it to be a trade secret. A critical review of the approach revealed a large number of examples from the literature where difficulties in obtaining reliable data defining the boundary systems were tackled by accepting controversial, incomplete, and inappropriate data (Zegada-Lizarazu et al., 2010)

To compute energy efficiency when knowledge of exact energy content of inputs is not known we consider another scenario when iso-energy lines have different slopes. The lowest of these lines, a dotted blue line in figure 1, touches the segmented frontier line at a different point – a farm that uses x_2 more than x_1. This is so because under the new scenario ratio of energy intensity of x_2 and energy intensity of x_1 is lower. Though technical efficiency of the farm Z remains the same, its allocative efficiency and therefore energy efficiency in this scenario is higher.

Data was collected in a survey of 21 public sector banana plantations in Latin America. Banana, the world's most popular fruit, is a tropical fruit that grows best at latitude 20 degrees north and south of equator. Ecuador and Colombia are the top two suppliers of banana to the European Union. The banana market is characterized by heavy horizontal and vertical integration within the value chain and a low-cost and highly competitive export market focused in Latin America. Bananas are typically grown on plantations, and certain viruses, pests and fungi have spread in epidemic proportions over the last few decades, allegedly a result of decreased immunity created by monoculture practices (Mlot, 2004). Increased susceptibility has rendered banana plantations increasingly dependent on agrochemicals with high energy content. In turn, the extensive use of agrochemicals has given rise to the emergence of pest strains that are resistant to pesticides, posing a problem to plantation managers seeking to reduce agrochemical use (Liu, 2009). Energy content of input available from the manufacturers and in the literature varies widely Minimum and maximum reasonable values were recorded from the studies in Denmark (Dalggaard et al., 2001), Baluchistan province of Iran (Amini & Ravandeh, 2015), Hamedan province of Iran (Mobtaker et al., 2010), Haryana, India (Singh, 2002) and Turkey (Akcaoz, 2011; Barut et al., 2011; Hatirliet al., 2005) These values and the averages are given Table 1.

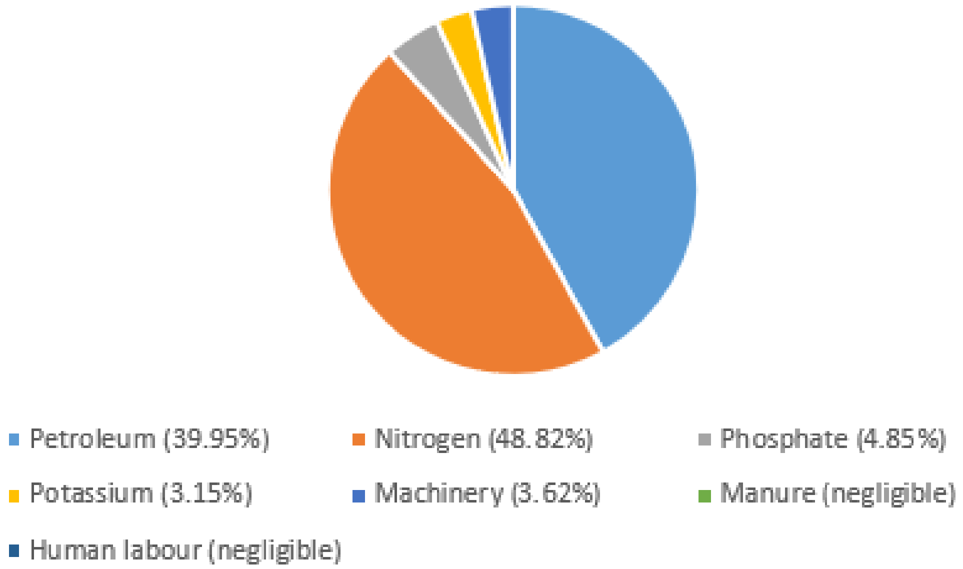
Table 1: Energy content of inputs in MJ per unit.

Input	Unit	Maximum	Minimum	Average
Diesel	litre	51.5	35.9	47.8
Machinery	hour	158.30		62.7

Nitrogen	kilogram	78.2	12.6	54.6
Phosphate	kilogram			9.9
Potassium	kilogram			9.1
Manure	ton			7.9
Labour	hour	1.9	0.2	0.3

The energy required for all farms with regard to five inputs, farmyard manure, chemical fertilizers, diesel fuel, machinery and human labour was calculated. The average of total input energy were found **as 50026 MJ per hectare**. As shown in Fig. 2, the amounts of nitrogen and fuel with just under 49% and 40% respectively had the maximum share among all input energy used in banana production. While the share of other chemicals (Phosphorus and Potassium) and of machinery was significant, the share of farmyard manure and human labour was negligible testifying the dependence on chemicals in modern agriculture.

Figure 2: Energy required for inputs



To examine energy efficiency in the deterministic case, we run the linear programming models following Färe et al. (1985) under the assumptions of constant returns to scale, convexity and strong disposability on input and output. The standard textbook equations are not being repeated here. We use the energy content of inputs given in the last column of Table 1. For the purpose of normalisation we divided the sum of the energy consumed in MJ by output of banana in kg. The minimum representing the most efficient farm was normalised to 1 in order to obtain an efficiency score for each farm. We find mean Technical Efficiency to be 0.70, Allocative efficiency to be 0.88 and Energy Efficiency to be 0.62 indicating a possibility of reduction in inputs and consequent energy consumption by as much as 38%.

Conclusion

Results indicate that energy inefficiency in modern agribusiness can be a result of mismanagement of inputs and/or their misallocation. The method given above can be applied to measure enery efficiency in the public sector enterprises. More importantly, the technique has to be extended to cover the cases where the energy content of inputs in uncertain.

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Author's note

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