Energy Efficiency and Shadow Costs of Energy Saving in Conventional Agricultural Production

The Case of Czech Wheat Production

Jarmila Curtiss[1), Ladislav Jelínek[2)

IAMO
LEIBNIZ INSTITUTE OF AGRICULTURAL DEVELOPMENT IN CENTRAL AND EASTERN EUROPE

IAEI

2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, USA, July 24-26, 2011

Motivation

Increasing worldwide energy demand and diminishing supplies of fossil fuels have necessitated the development and increasing use of new sustainable energy sources, as well as more parsimonious energy use. In the context of agriculture, research has focused predominantly on the production of bio-energy, while only a limited number of studies have investigated the energy use and possible energy saving in conventional agricultural production. The lack of empirical research on the energy saving potential in agriculture, costs of energy use optimization, and the determinants of energy use reduction motivated this study.

Objectives

I. To measure the farm-level energy and cost efficiency of conventional agricultural (wheat) production.
II. To identify the potential for energy saving in conventional agriculture and quantify its shadow cost.
III. To identify production technologies and managerial practices that reduce total energy use.

Theoretical concept

Production material (energy) balance condition

$a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 = by + r$

a, b – energy coefficients
x_1 – direct renewable inputs (e.g., sunlight, warmth, land nutrition)
x_2 – direct non-renewable inputs (e.g., fertilizers, feed)
x_3 –indirect renewable inputs (e.g., labor, management)
x_4 – indirect non-renewable inputs (e.g., machinery, equipment, pesticides, fuel)
y – output
r – energy residue

=> allows application of method by Coelli, Lauwers, Van Huylenbroeck (2007) introducing analogy between cost and nutrient minimization to measure polution reduction potential and its cost.

Energy efficiency of production

Ratio of minimum non-renewable energy to observed non-renewable energy at given production level => $EE = a'x_e/a'x$

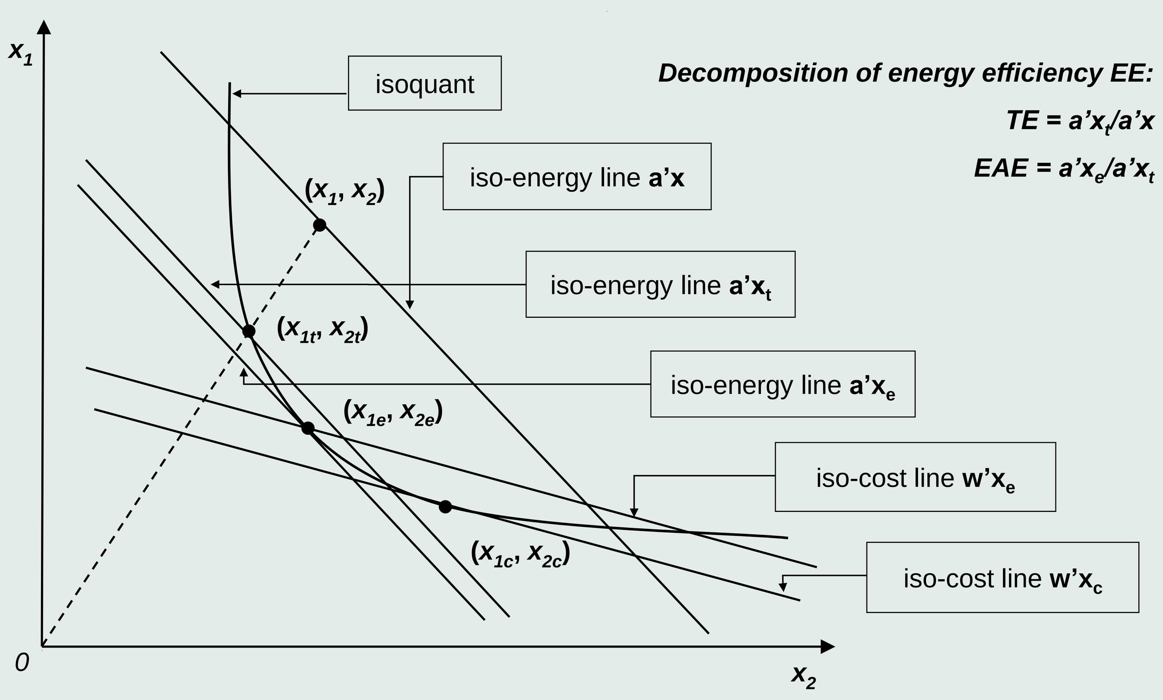
Cost efficiency of production

Ratio of minimum cost of non-renewable inputs to observed cost of non-renewable inputs at given production level => $CE = w'x_c/w'x$

Shadow cost of energy optimal production

Difference between costs of energy-optimal and cost-optimal input use => $w'x_e - w'x_c$

Cost and energy minimization – two input case



Source: Adjusted figure from Coelli, Lauwers, Van Huylenbroeck (2007)

Data

(a) Survey data on wheat production, input quantities and price, production technologies and conditions, farm type and managerial practices for 95 farms for production year 2007/08.
(b) Energy coefficients for individual non-renewable inputs from the PLANETE methodology (Méthode Pour L'Analyse EnergéTique de l'Exploitation) developed by SOLAGRO.

Method

Data envelopment analysis - DEA (input oriented, CRTS)
– To estimate technical efficiency*, and feasible minimal energy use[1) and costs[2) for observed wheat production**.

* $\min_{\theta,\lambda} \theta$
s.t.
$$-y_i + Y\lambda \geq 0,\quad \theta x_i - X\lambda \geq 0,\quad \lambda \geq 0$$

**1) $\min_{\lambda, x_i^e} (a_i' x_i^e)$
s.t.
$$-y_i + Y\lambda \geq 0,\quad x_i^e - X\lambda \geq 0,\quad \lambda \geq 0$$

**2) $\min_{\lambda, x_i^c} (w_i' x_i^c)$
s.t.
$$-y_i + Y\lambda \geq 0,\quad x_i^c - X\lambda \geq 0,\quad \lambda \geq 0,$$

Truncated regression
- To identify statistically significant determinants of *EE.*

DEA results

Figure 1: Technical, cost and energy efficiency scores for Czech farms' wheat production in 2007/08

	Mean	St. dev.
Technical efficiency	0.739	0.157
Allocative cost efficiency	0.822	0.102
Total cost efficiency	0.604	0.141
Allocative energy efficiency	0.734	0.143
Total energy efficiency	0.537	0.153

Figure 2: Input related cost and energy efficiency scores for Czech farms' wheat production in 2007/08

	Seeds	Fertilizers & chemicals	Machinery	Fuel
Cost-minimal input level /observed input level				
	0.47	0.60	0.80	0.27
Energy-minimal input level /observed input level				
	0.52	0.49	0.97	0.51

Figure 3: Comparative analysis of cost and energy optima and shadow cost of energy use optimization in Czech farms' wheat production in 2007/08

	2007/08
Cost in energy optimum/min. cost	1.09
Minimal energy consumption/energy consumption in cost optimum	0.96
Shadow cost of energy optimal production in CZK/ha ($/ha)	736.9 (41)
Shadow cost of energy optimization in CZK/GJ ($/GJ)	1567.8 (87)

Truncated regression results – energy efficiency determinants

Variable	Effect	Variable	Effect
First productive fertilizing	- -	Farm size (in arable land)	+ +
Late regenerative fertilizing	+ +	Legal for Limited Liability Company	-
Other (mainly qualitative) fertilizing	+ +	Number of workers (employees)	- -
Doubled gearing during fertilizing	-	Rate of optimal timing of technological operations	- -
Combination of liquid fertilizers with plant protection chemicals	- -	Shortening of transportation distances through straightening of material flows	+ +
Liquid manure fertilizing within the last two years	- -	Share of crop production in total agricultural production	- -
Conventional soil preparation, separate sowing	- -	Increased use of transportation vehicles with higher utility weight	+ +
Soil-preserving technology of soil preparation with shallow soil loosening to the depth of sowing	+ +	Need of utilizing technical and operational possibilities of machinery and equipment	- -
Preventive and corrective management of soil erosion	+ +		

Note: Only significant variables presented (e.g., precision farming was found to have insignificant effect on *EE*). Effect signs imply: -, - - negative statistically significant effect on 5% and 1% significance level, respectively. Analogically, + and ++ for positive effect.

Conclusions

• There are significant differences in energy consumption per unit of wheat production among Czech farms - best producers consume 46% less energy per unit of production than average producers; however, from that ca. 30% is due to variation in production conditions (beyond farmers' control) • Marked share of energy inefficiency (over 50% of potential energy savings) originates in technical efficiency (simultaneous cost-saving potential) • Czech farms produce wheat with a combination of inputs that is closer to cost than energy optima • Producing wheat in energy optimum would increase costs by 9% (compared to the min. prod. costs) • The largest potential of energy savings was found in fuel, and fertilizers and other chemicals • Implications: support of investment in more fuel-efficient machinery or machinery with other energy-saving technical parameters (e.g., higher utility weight); increase awareness of negative energy effects of some commonly applied technological practices, emphasize the need of optimizing material transport • Methodological challenges: detailed data demand, information lost through aggregation, DEA sensitivity to outliers, renewable inputs subject to cost optimization.

1) Leibniz Institute of Agricultural Development in CEE | Theodor-Lieser-Str. 2, 06120 Halle, Germany | curtiss@iamo.de | www.iamo.de
2) Institute of Agricultural Economics and Information | Mánesova 75, Praha 2, 120 58, Czech Rep. | jelinek.ladislav@uzei.cz | www.uzei.cz

Acknowledgement: This research was carried out within the project "Economic system of evaluation of farm performance with respect to sustainable use of natural resources", Nr.: QH71016, funded by the Czech National Agency for Agricultural Research. The authors thank the Agency and other project team members for their significant contribution to questionnaire development, survey organization, data processing, and for providing energy input data from the PLANETE methodology.