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

The Case of Czech Wheat Production

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**Motivation**

Increasing worldwide energy demand and diminishing supplies of fossil fuels have necessitated the development and increasing use of new 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.

**Theoretical concept**

**Production material (energy) balance condition**

\[ \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 x_4 + \alpha_5 x_5 = b + r \]

- \( \alpha \): energy coefficients
- \( x \): direct renewable inputs (e.g., sunlight, warmth, land nutrition)
- \( x \): direct non-renewable inputs (e.g., fertilizers, feed)
- \( x \): indirect non-renewable inputs (e.g., labor, management)
- \( x \): indirect non-renewable inputs (e.g., machinery, equipment, pesticides, fuel)
- \( r \): output
- \( r \): energy residue

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

**Energy efficiency of production**

Ratio of minimum non-renewable energy to observed non-renewable energy at given production level \( \Rightarrow EE = \alpha x / a x \)

**Cost efficiency of production**

Ratio of minimum cost of non-renewable inputs to observed cost of non-renewable inputs at given production level \( \Rightarrow CE = W x / m x \)

**Shadow cost of energy optimal production**

Difference between costs of energy-optimal and cost-optimal input use \( \Rightarrow W x - W x \)

**Method**

**Data envelopment analysis - DEA (input oriented, CRTS)**

- To estimate technical efficiency *, and feasible minimal energy use1 and costs2 for observed wheat production**.

\[
\begin{align*}
\text{min}_{x_1} & \theta \quad \text{(1)} \\
\text{min}_{x_2} & (\alpha x') \quad \text{(2)} \\
\text{min}_{x_3} & (w x') \\
\text{s.t.} & \quad y_1 + y_2 = 0, \\
& \quad y_1 + y_2 = 2, \\
& \quad y_1 + y_2 = 0, \\
& \quad x' - x_1 = 0, \\
& \quad x_1 = 0, \\
& \quad \eta = 0.
\end{align*}
\]

**Truncated regression**

- To identify statistically significant determinants of EE.

**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.

**Truncated regression results – energy efficiency determinants**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Effect</th>
<th>Variable</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>First productive fertilizing</td>
<td>- -</td>
<td>Farm size (in arable land)</td>
<td>++</td>
</tr>
<tr>
<td>Late regenerative fertilizing</td>
<td>++</td>
<td>Legal for Limited Liability Company</td>
<td>-</td>
</tr>
<tr>
<td>Other (mainly qualitative) fertilizing</td>
<td>++</td>
<td>Number of workers (employees)</td>
<td>- -</td>
</tr>
<tr>
<td>Doubled geared during fertilizing</td>
<td>-</td>
<td>Rate of optimal timing of technological operations</td>
<td>- -</td>
</tr>
<tr>
<td>Combination of liquid fertilizers with plant protection chemicals</td>
<td>- -</td>
<td>Shortening of transportation distances through straightening of material flows</td>
<td>++</td>
</tr>
<tr>
<td>Liquid manure fertilizing within the last two years</td>
<td>-</td>
<td>Share of crop production in total agricultural production</td>
<td>- -</td>
</tr>
<tr>
<td>Conventional soil preparation, separate sowing</td>
<td>--</td>
<td>Increased use of transportation vehicles with higher utility weight</td>
<td>++</td>
</tr>
<tr>
<td>Soil-preserving technology of soil preparation with shallow soil loosening to the depth of sowing</td>
<td>++</td>
<td>Need of utilizing technical and operational possibilities of machinery and equipment</td>
<td>- -</td>
</tr>
<tr>
<td>Preventive and corrective management of soil erosion</td>
<td>++</td>
<td></td>
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</tr>
</tbody>
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Note: Only significant variables presented (e.g., precision farming was found to have insignificant effect on EE). Effect sign imply: -, - - negative statistically significant effect on 5% and 1% significance level, respectively. Analogically, + and ++ for positive effect.

**DEA results**

<table>
<thead>
<tr>
<th>Source</th>
<th>Mean</th>
<th>St. dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of input level / observed input level</td>
<td>0.47</td>
<td>0.60</td>
</tr>
<tr>
<td>Energy-minimal input level / observed input level</td>
<td>0.52</td>
<td>0.49</td>
</tr>
<tr>
<td>Total energy efficiency</td>
<td>0.537</td>
<td>0.153</td>
</tr>
</tbody>
</table>

| Cost-minimal input level | 0.60 |
| Energy-minimal input level | 0.80 |
| Total energy efficiency | 0.96 |
| Shadow cost of energy optimal production in CZK/ha ($/ha) | 736.9 |
| Shadow cost of energy optimization in CZK/GJ ($/GJ) | 1567.8 |

**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 the above, it can be concluded that significant amounts of energy can be saved (comparing to the min. prod. costs).
- The largest potential of energy savings was found in fuel, and fertilizers and other chemicals.
- Implications of this research: support of investment in more fuel-efficient machinery or machinery with other energy-saving technical parameters (e.g., higher utility weight);
- Increase of awareness of negative energy effects of some commonly applied technological practices.
- Methodological challenges: detailed data demand, information lost through aggregation, DEA sensitivity to outliers, renewable inputs subject to cost optimization.

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**Figure 1: Technical and cost efficiency scores for Czech farms’ wheat production in 2007/08**

- Technical efficiency: 0.734
- Allocative cost efficiency: 0.96
- Total cost efficiency: 0.80
- Allocative energy efficiency: 0.96
- Total energy efficiency: 0.80

**Figure 2: Input related cost and energy optimza and shadow cost of energy use optimization in Czech farms’ wheat production in 2007/08**

- Cost of input level: 0.60
- Energy-minimal input level: 0.80
- Total energy efficiency: 0.96
- Shadow cost of energy optimal production in CZK/ha ($/ha): 736.9
- Shadow cost of energy optimization in CZK/GJ ($/GJ): 1567.8

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

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