Shadow Pricing of Energy-related Carbon Emission in Agriculture: An Adaptive Approach

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Motivation (Empirics)

- creation of the zero-carbon economy
- Strategy Europe 2020, European Green Deal
- Zero-carbon economy can be achieved via
  - modernization of the energy supply (energy-mix changes),
  - improvement of the technologies (carbon factor changes) and energy efficiency.
- Agricultural sector is important in terms of food security and rural development objectives.
- In the case of the European Union (EU), support is distributed under the Common Agricultural Policy (CAP).

Motivation (Methodology)

- Production frontier
- Environmental Production Technology
- The trade-off -- shadow pollution cost
- The environmental production technologies can be approximated parametrically or nonparametrically.
  - The stochastic parametric estimation is found in Pittman (1981), Reinhard et al. (1999) or Cuesta et al. (2009).
  - The deterministic parametric approach was discussed by Färe et al. (2006).
  - The nonparametric environmental production technologies can be defined following Hailu and Veeman (2001), Färe and Grosskopf (2003) or Murty et al. (2012).
- In this research, we follow the nonparametric estimation (Data Envelopment Analysis – DEA).

Methodological Approach

- Directional DEA models and distance functions were developed by Chambers et al. (1996, 1998) mimicking the benefit functions.
- Chung et al. (1997) adapted the directional DEA to the case of the environmental production technology.
- The directional DEA can measure the efficiency of decision making units towards different directions. .
- the directions can be observation-specific or common to the whole sample.
- In this paper, we seek to ascertain the effects of using the different directions on the GHG emission shadow prices
- Weak disposability DEA model proposed by Kuosmanen (2005) is applied.
- The different directions for optimization are assumed to obtain the shadow prices of the energy-related GHG emission in the EU agriculture.
- The country-level data are used for the analysis

Environmental Production Technology

- Transformation approach (Seiford, Zhu, 2002)
- Strong disposability (Hailu, Veeman, 2001)
- **Weak disposability (Färe, Grosskopf, 2003)**
- Multi-output technology structure (Cherchye et al., 2015)
- G-disposability (Rødseth, 2017)
- By-production technology (Murty et al., 2012)

Weak Disposability technology (Kuosmanen, 2005)

- input quantities $x = (x_1, x_2, \dots, x_N)$
- desirable output quantities $y = (y_1, y_2, \dots, y_M)$
- undesirable output quantities $z = (z_1, z_2, \dots, z_J)$
- technology $T = \{(x, y, z) : x \text{ can produce } (y, z)\}$
- DEA approximation of *T*:

$$\hat{T} = \left\{ (x, y, z): \begin{array}{l} \sum_{k=1}^{K} \theta_k \xi_k y_k \geq y,\ \sum_{k=1}^{K} \xi_k x_k \leq x,\ \sum_{k=1}^{K} \theta_k \xi_k z_k = z, \\ \sum_{k=1}^{K} \xi_k = 1,\ \xi_k \geq 0, 0 \leq \theta_k \leq 1, k = 1, \dots, K \end{array} \right\}$$

- Linearization:

$$\hat{T} = \left\{ (x, y, z): \begin{array}{l} \sum_{k=1}^{K} \lambda_k y_k \geq y,\ \sum_{k=1}^{K} (\lambda_k + \sigma_k) x_k \leq x,\ \sum_{k=1}^{K} \lambda_k z_k = z, \\ \sum_{k=1}^{K} (\lambda_k + \sigma_k) = 1,\ \lambda_k, \sigma_k \geq 0, k = 1, \dots, K \end{array} \right\}$$

- directional output distance function

$$D(x, y, z; g_y, g_z) = \max\left\{ \delta : (x, y + \delta g_y, z - \delta g_z) \in T \right\}$$

DEA models

- Primal

$$D(x,y,z;\, g_y, g_z) \;=\; \max_{\delta,\lambda,\sigma} \delta$$

s.t.

$$\sum_{k=1}^{K} \lambda_k y_k^m \geq y_{k'}^m + \delta g_y^m, m = 1,\ldots,M$$

$$\sum_{k=1}^{K} (\lambda_k + \sigma_k) x_k^n \leq x_{k'}^n, n = 1,\ldots,N$$

$$\sum_{k=1}^{K} \lambda_k z_k^j = z_{k'}^j - \delta g_z^j, \; j = 1,\ldots,J$$

$$\sum_{k=1}^{K} (\lambda_k + \sigma_k) = 1$$

$$\lambda_k, \sigma_k \geq 0, k = 1,\ldots,K$$

$$\sum_{k=1}^{K} \lambda_k z_k^j \leq z_{k'}^j - \delta g_z^j, \; j = 1,\ldots,J$$

Non-negativity of the shadow values

$$CSP = \frac{\pi_z^j}{\pi_y^m}$$

- Dual

$$D\;(x\;,y\;,z\;;\, g_y, g_z) = \min_{\pi_y, \pi_x^n, \pi_x^p, \pi_z, \phi} \phi - \Big(\sum_{m=1}^{M} \pi_y^m y_{k'}^m - \sum_{n=1}^{N} \pi_x^n x_{k'}^n - \sum_{j=1}^{J} \pi_z^j z_{k'}^j\Big)$$

s.t.

$$\sum_{m=1}^{M} \pi_y^m y_k^m - \sum_{n=1}^{N} \pi_x^n x_k^n - \sum_{j=1}^{J} \pi_z^j z_k^j \leq \phi, k = 1,\ldots,K$$

$$-\sum_{n=1}^{N} \pi_x^n x_k^n \leq \phi, k = 1,\ldots,K$$

$$\sum_{m=1}^{M} \pi_y^m g_y^m + \sum_{j=1}^{J} \pi_z^j g_z^j = 1$$

$$\pi_y^m \geq 0, m = 1,\ldots,M$$

$$\pi_x^n \geq 0, n = 1,\ldots,M$$

$$\pi_z^j \geq 0, \; j = 1, 2, \ldots, J$$

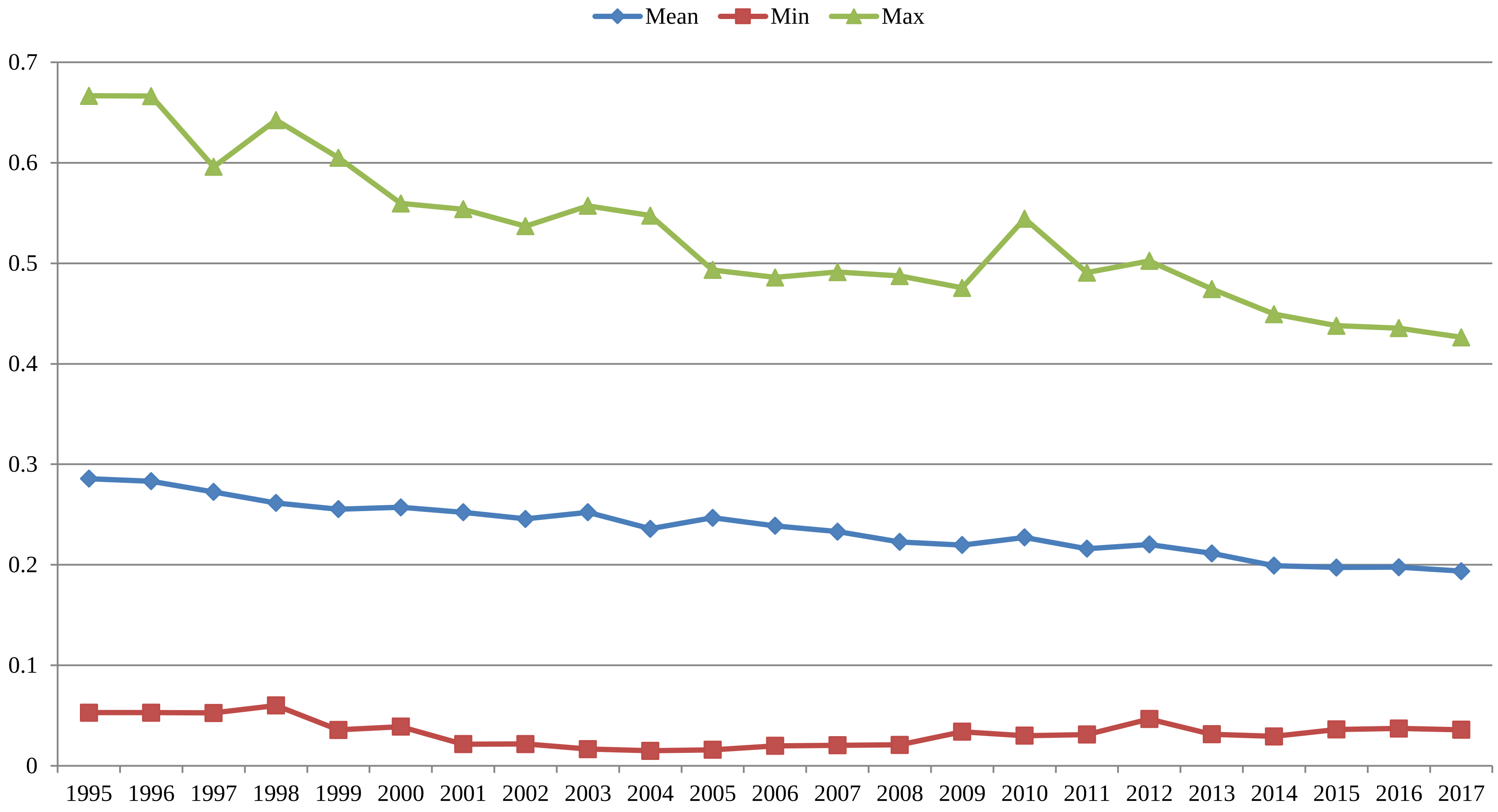
Directions (for optimization)

- Proportional $(g_y, g_z) = (y_k, z_k)$
- Unit vectors $(g_y, g_z) = (1,1)$
- Aggregate vector $(g_y, g_z) = \left(\sum_{k=1}^{K} y_k, \sum_{k=1}^{K} z_k \right)$
- Average vector $(g_y, g_z) = \left(\frac{1}{K} \sum_{k=1}^{K} y_k, \frac{1}{K} \sum_{k=1}^{K} z_k \right)$

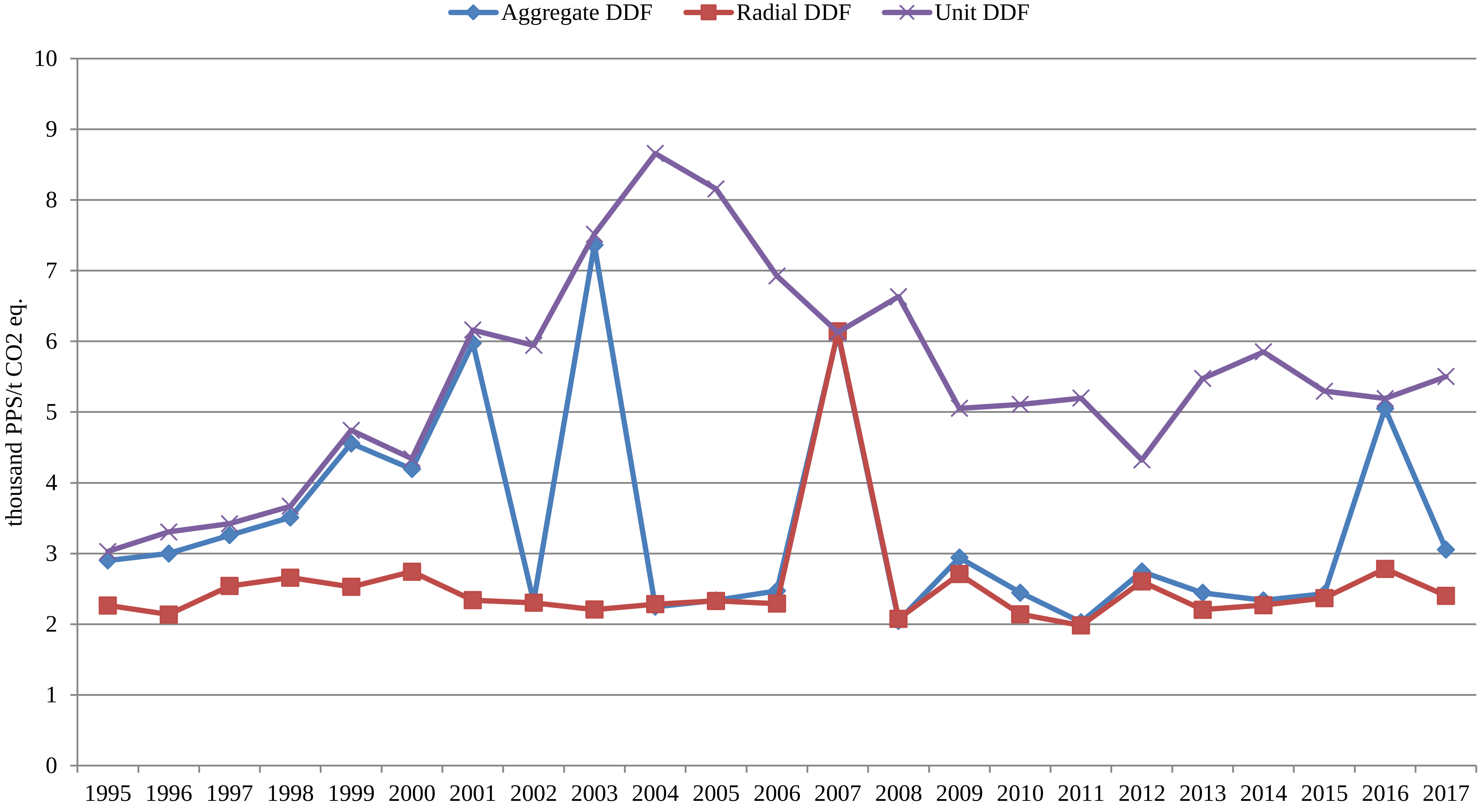
Data Used

- This paper assesses the shadow prices of the energy-related GHG emission in the European agriculture.
- Inputs:
  - labour (in Annual Work Units),
  - land area (hectares),
  - intermediate consumption (PPS of 2010, less energy expenses)
  - energy (tonnes of oil equivalent)
- Desirable output is the agricultural output (PPS of 2010)
- The undesirable output is the energy-related GHG emissions (t CO_2 equivalent).
- The data are taken from the economic accounts for agriculture, environmental accounts, agricultural statistics and energy balances provided by Eurostat.
- The data cover years 1995-2017.

Energy-related GHG emission intensity in the selected EU countries, 1995-2017



The mean shadow prices of the energy-related GHG emission in European agriculture, 1995-2017

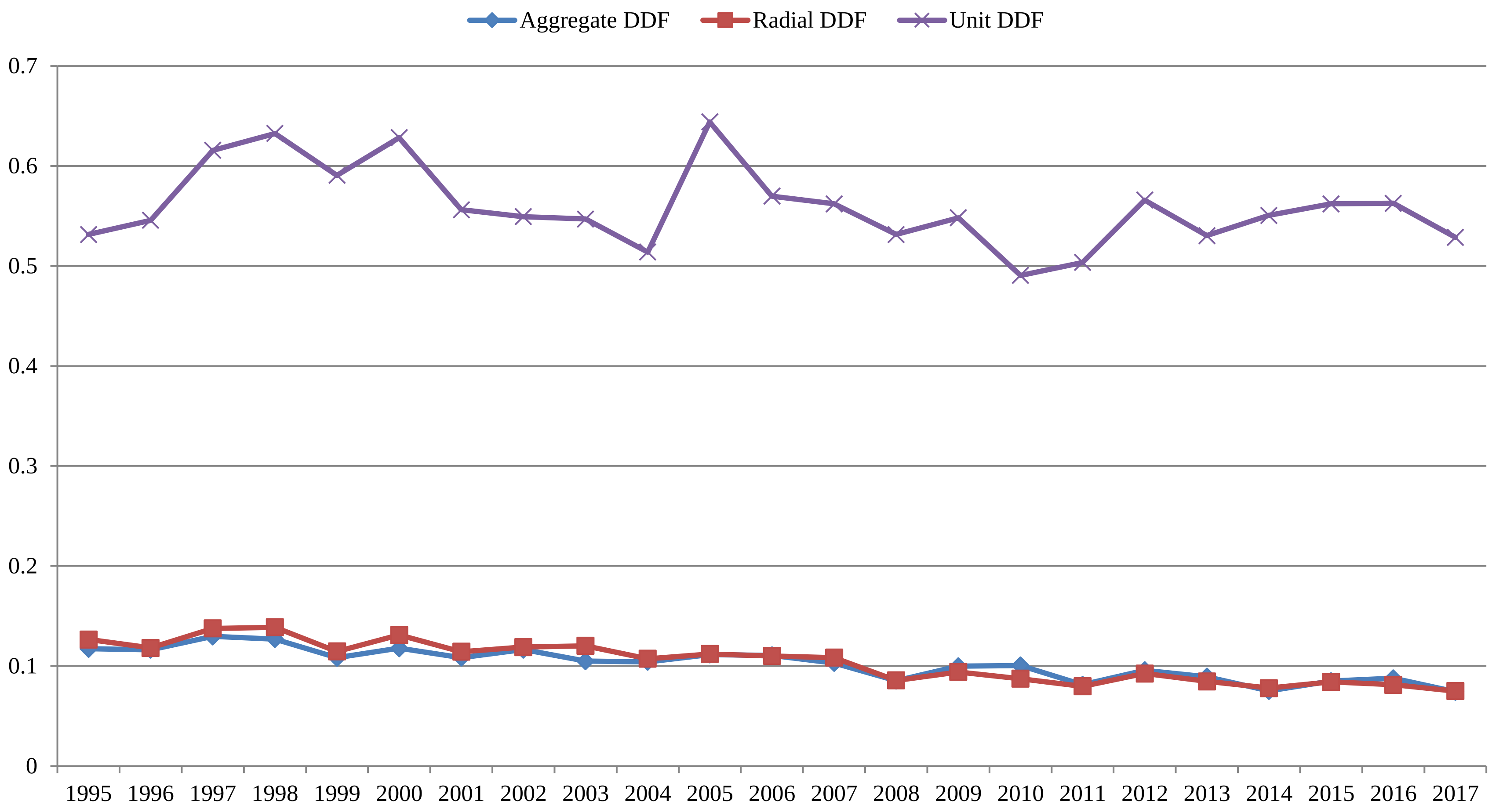


Note: the mean value is based on the weighted average where the agricultural output shares are used as country-specific weights.

The average shadow price (PPS of 2010/kg CO$_2$ eq.) and its trend (% per year), 1995-2017

Country	Aggregate DDF		Radial DDF		Unit DDF	
	Average	Trend	Average	Trend	Average	Trend
Austria	2.4	0.1	2.3	0.0	2.4	0.0
Belgium	1.9	3.8	2.2	3.8	2.2	3.5
Bulgaria	3.1	2.2	2.7	1.4	3.5	1.8
Czechia	2.4	-1.1	2.5	-1.5	2.8	-0.8
Denmark	2.6	3.6	2.6	4.7	2.7	4.9
Estonia	4.5	-4.4	3.3	2.0	5.1	-3.0
Finland	0.7	4.0	1.2	1.0	2.0	0.8
France	3.6	0.8	3.8	-0.3	3.7	1.0
Greece	2.2	11.4	2.0	10.3	3.8	14.8
Hungary	3.5	-1.1	3.4	-0.8	3.7	-0.8
Ireland	2.8	4.2	2.7	3.5	3.0	4.3
Italy	3.1	0.2	3.0	-2.9	2.4	-2.2
Latvia	1.1	13.5	1.2	12.8	2.4	10.6
Lithuania	4.9	4.0	4.6	5.9	8.8	4.2
Netherlands	1.5	0.7	1.5	0.7	1.3	1.4
Poland	0.0	-	0.0	-	1.1	2.8
Portugal	2.2	-0.2	1.7	-3.7	2.8	3.0
Romania	15.1	-4.9	5.7	0.5	35.0	0.8
Slovakia	7.3	-8.1	5.1	2.0	8.2	-6.4
Slovenia	3.9	-0.1	4.1	4.0	4.9	1.1
Spain	0.2	-2.5	0.2	-4.1	0.4	-2.0
Sweden	0.7	-10.4	0.8	-9.5	1.5	-4.1
UK	2.6	3.3	2.6	3.4	2.6	2.8
Average	3.1	0.9	2.6	1.5	4.6	1.7
Weighted av.	2.0	0.5	1.9	-0.2	2.5	1.2

The relative total abatement cost (weighted average) for 1995-2017

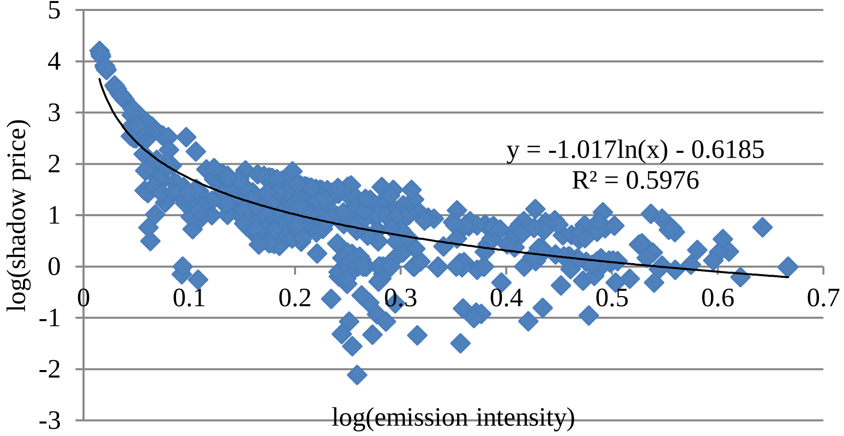


The relative total abatement cost (factor) and its trend (p.p. per year), 1995-2017

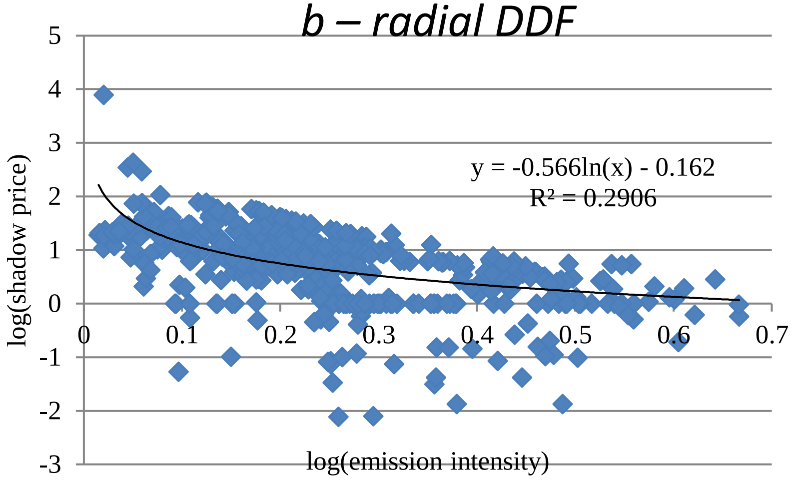
Country	Aggregate DDF		Radial DDF		Unit DDF	
	Average	Trend	Average	Trend	Average	Trend
Austria	0.45	-0.7	0.45	-0.8	0.45	-0.8
Belgium	0.67	0.9	0.75	0.5	0.75	0.5
Bulgaria	0.25	-0.3	0.22	-0.5	0.22	-0.5
Czechia	0.60	-2.4	0.61	-2.7	0.61	-2.7
Denmark	0.77	-0.3	0.73	0.7	0.73	0.7
Estonia	0.86	-1.1	0.72	2.7	0.72	2.7
Finland	0.33	0.6	0.63	-0.6	0.63	-0.6
France	0.75	0.1	0.79	-0.8	0.79	-0.8
Greece	0.26	0.1	0.24	-0.1	0.24	-0.1
Hungary	0.43	-1.4	0.41	-1.2	0.41	-1.2
Ireland	0.45	0.6	0.42	0.3	0.42	0.3
Italy	0.56	-0.6	0.57	-2.3	0.57	-2.3
Latvia	0.27	3.3	0.29	3.3	0.29	3.3
Lithuania	0.36	0.0	0.33	0.6	0.33	0.6
Netherlands	0.71	-0.3	0.71	-0.2	0.71	-0.2
Poland	0.00	0.0	0.00	0.0	0.00	0.0
Portugal	0.35	-0.4	0.27	-1.3	0.27	-1.3
Romania	0.50	-3.8	0.18	-0.4	0.18	-0.4
Slovakia	0.67	-1.7	0.61	2.8	0.61	2.8
Slovenia	0.79	-0.8	0.81	2.6	0.81	2.6
Spain	0.06	-0.2	0.06	-0.3	0.06	-0.3
Sweden	0.29	-3.1	0.34	-3.4	0.34	-3.4
UK	0.60	1.1	0.59	1.1	0.59	1.1
Average	0.48	-0.5	0.47	0.0	0.47	0.0
Weighted av.	0.43	-0.2	0.44	-0.5	0.44	-0.5

MAC Curves

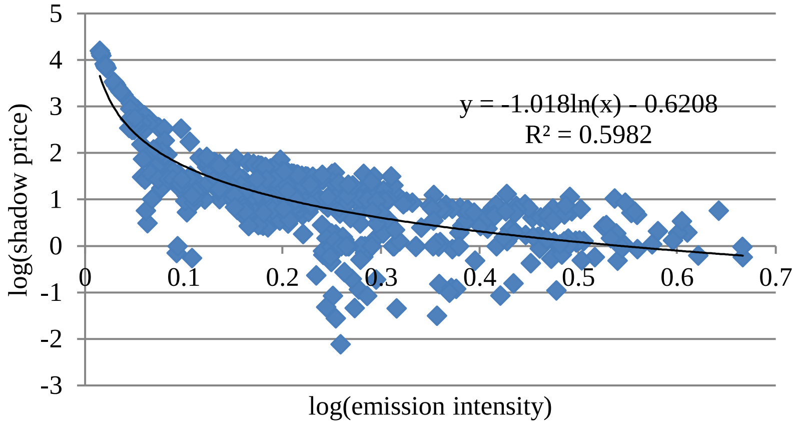
a – aggregate DDF



b – radial DDF



c – unit DDF



Conclusions

- The results showed that the level of the energy-related GHG emission shadow price depended on the direction taken. Indeed, the radial directional output distance function showed the lowest shadow price levels as it corresponds to the data structure to the highest extent.
- The highest average shadow price observed in Poland and Spain implies that these countries require much attention to their energy-related GHG emission in agriculture. On the contrary, the highest shadow prices were observed for Romania and Slovakia which do not require much effort towards curbing the energy-related GHG emission in the short term.
- The marginal abatement cost curves were also estimated based on the shadow prices rendered by each of the three directional DEA models. The results suggest that energy planning and climate change mitigation policy requires considering both the analytical tools and measures used for the analysis in order to properly address the challenges specific for different countries.
- The decision makers shaping the agricultural support policy in the European Union, the Common Agricultural Policy, could take the carbon shadow prices in the consideration when identifying the support measures (especially, the Pillar 2 ones). The similar experience can also be used for the agricultural support programmes envisaging rural development measures across different regions. The marginal abatement cost curves are also useful in providing rationale for the desirable level of the energy-related emission abatement.
- This paper embarked on nonparametric analysis. Further studies could explore the patterns of the energy-related GHG emission in agriculture by using the parametric distance functions. Also, further analysis is possible by exploiting micro-data. This would allow assessing energy consumption in different farming types.

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