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Structural and weather-related factors of the sustainable intensification process in agriculture of the European Union regions

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Electronic supplementary material

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SI indicator. The proposed measurement method consists of three stages. In the first, socio-economic and environmental input productivity indices are estimated using Färe-Primont TFP index, which is multiplicatively complete, and allows intertemporal comparison of the results (O'Donnell 2011). An R code to estimate SI index is provided in supplementary materials. It is estimated according to formula:

$$MFP_{hs,it} = \frac{D_0\left(x_0, q_{it}, t_0\right)}{D_0\left(x_0, q_{hs}, t_0\right)} \times \frac{D_I\left(x_{hs}, q_0, t_0\right)}{D_I\left(x_{it}, q_0, t_0\right)} \quad \text{(S1)}$$

where: t_0– representative time period; x_0, q_0 – fixed vectors of representative quantities of inputs and outputs.

For representative a mean value for all time periods and observations is used. Subscript *it* refers to *i*-th observation in *t*-th period, while *hs* subscript describes another *h*-th firm in *s*-th period. D_0 and D_I refer to input and output distance functions, which play a role of aggregators for inputs and outputs. Distance functions were estimated using non-parametric data envelopment analysis (DEA) approach. Linear problems solved to achieve the values of distances are described in details in O'Donnell (2011). Distances were calculated under variable returns to scale (VRS) assumption and for socio-economic component output orientation was assumed, while for environmental component model was oriented on inputs minimisation. This assumption is arising from eco-efficiency approach, where environmental pressures are included into the model as inputs, used to generate economic outcome, and the goal is to minimise environment depletion keeping production on the assumed level. Färe-Primont index was calculated basing on "productivity" package prepared by Dakpo et al. (2018).

In the second step, the optimal path for sustainable intensification (SI) is identified. To determine it, the baseline socio-economic and environmental efficiency values estimated for the Färe-Primont index determination were used. These indices take values in the interval $\langle 0,1 \rangle$ and can be used as coordinates in a two-dimensional system (Figure S1A). The optimal path of sustainable intensification is determined by the angle α_{opt}, which describes the slope of the line leading from the point *a* described in the coordinate system by the values of socio-economic (x_a) and environmental (y_a) efficiency to the point *e* with coordinates (1,1), representing full efficiency in both dimensions. The value of the angle α_{opt} can be determined by a function [Equation (S2)]

The resulting angle is determined by the proportion in which the values of the environmental and socio-economic productivity indices of the agricultural sector should be in relation to each other in order for it to reach full efficiency as quickly as possible. For example, if point a had coordinates (0.8, 0.6), this would mean that the farm a, in order to be fully efficient, should generate 20% more social and economic output using its current level of economic inputs and generate current level of economic output using 40% less environmental resources than it does at present. The inefficiency in the use of environmental resources is therefore greater, so to achieve full efficiency it should decrease faster, exactly twice as fast (40 / 20 = 2). In turn, according to equation (S2), the value of α_{opt} for this value will be 64.43°.

The function $f(x_a, y_a)$ also has several special cases. If a country's agricultural sector is characterised by full economic input efficiency in the baseline period, then progress in environmental input efficiency is assumed to be optimal while maintaining the current level of economic input efficiency, which is described by $\alpha_{opt} = 90°$ (vertical line). Similarly, in the case of full environmental input efficiency, only increasing economic input efficiency is postulated, which is described by $\alpha_{opt} = 0°$ (horizontal line). When a sector makes optimal use of both economic and environmental resources, then further equal development in both areas is postulated ($\alpha_{opt} = 45°$).

In the third step, a synthetic indicator is estimated. The method of estimation can be illustrated in a coordinate system (Figure S1B). Points *a* and *b* represent the two countries analysed. Their distances from the origin of the coordinate system horizontally (segments 0*xa*, 0*xb*) represent the change in socio-economic agricultural productivity, while the distance vertically (segments 0*ya*, 0*yb*) represents the change in environ-

$$\alpha_{opt} = f\left(x_a, y_a\right) = \begin{cases} arctg\left(\dfrac{1-y_a}{1-x_a}\right), & x_a < 1 \cap y_a < 1 \\ 0^\circ, & x_a < 1 \cap y_a = 1 \\ 45^\circ, & x_a = 1 \cap y_a = 1 \\ 90^\circ, & x_a = 1 \cap y_a < 1 \end{cases} \quad \text{(S2)}$$

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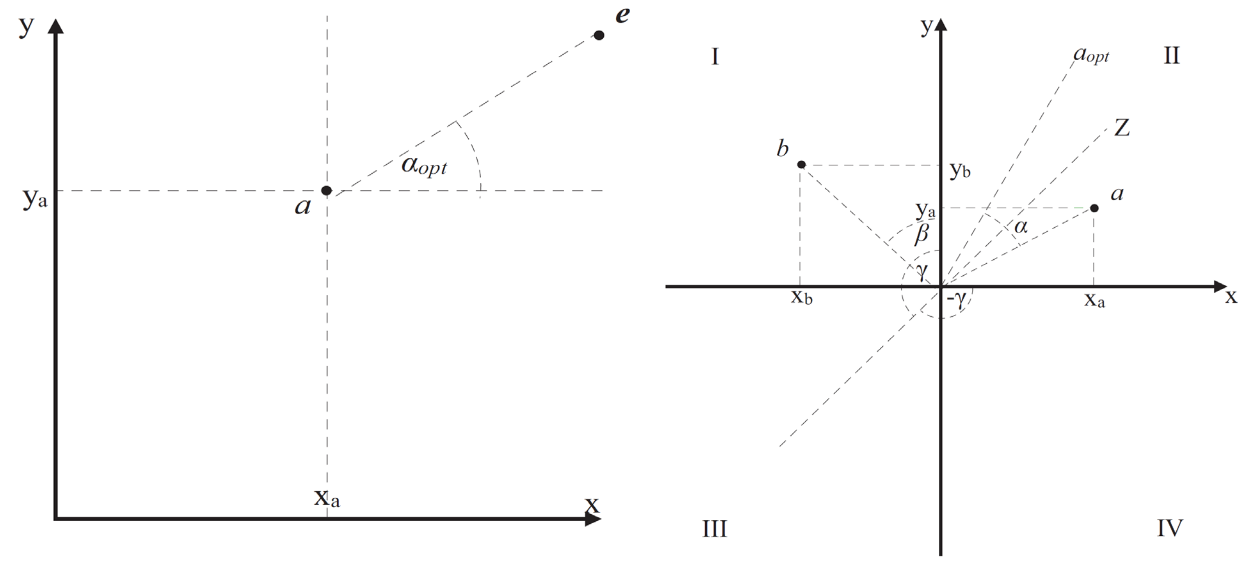

Figure S1. Sustainable intensification indicator – illustration of the model

Source: own study

mental productivity. The resultant change in both these dimensions can be calculated using the Euclidean metric, according to the formula:

$$d\left(x_n, y_n\right) = \sqrt{x_n^{\ 2} + y_n^{\ 2}} \quad \text{(S3)}$$

In Figure S1B this distance is represented by segments 0*a* and 0*b*. However, stopping at this method of dimension reduction is insufficient. Identical values for an index constructed in this way would have all observations located on a circle with centre at the origin of the coordinate system and radius 0*a*. This means that changes involving an improvement in both productivity dimensions would be assessed in the same way as those involving a "double" deterioration. It is therefore necessary to take additional account of the direction of the changes taking place. A proposed way to address this problem is to take into account the so-called directional multiplier (*Mk*). It is estimated in different ways, depending on the position of the object in question in a certain part of the coordinate system. *Mk* takes values in the interval $\left\langle -2,0\right) \cup \left\langle 1,2\right\rangle$. The prerequisite for its positive value is an increase in economic and environmental productivity, which is equivalent to the location of a point in the second part of the system. All points located there can be considered to represent changes towards sustainable intensification. A sufficient condition for obtaining the maximum value of *Mk* is that the slope of section 0*a* is consistent with the optimal path of sustainable intensification (α = 0). As one deviates from this path, the value of *Mk* decreases at a rate of about 0.011 ($\frac{1}{90}$) per 1° of deviation. The method of calculating *Mk*, can be written as a function of *f* (α), according to the formula:

$$Mk = f\left(\alpha\right) = 2 - \frac{\alpha}{90^{o}} \quad \text{(S4)}$$

If the necessary condition for sustainable intensification is not met ($x_n < 0 \cup y_n < 0$), the calculation of *Mk* changes. If the point representing the agricultural sector of a country is located in the I, III or IV part of the coordinate system, it is assumed that it is more important to stop the decline in economic productivity and environmental productivity as quickly as possible. In this situation, the reference path becomes the *Z* line, inclined at 45° to the *x* axis. Deviations from it (reduced by 45°) represent deviations from the path that guarantee that economic or environmental performance is at least maintained at the level of the base period. For point b, located in the first part of the system and therefore characterised by a positive environmental productivity index and a negative economic productivity index, this will be the angle β. This angle takes values in the range $\left\langle -135°, 135°\right)$. For points above the *Z*-straight line, these are positive values, while for points below the *Z* line, these are negative values. The 0° angle is expressed

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by the x and y axes. The angle measure β, expressed in degrees, was then scaled according to the function:

$$Mk = f(\beta) = \begin{cases} -\dfrac{\beta}{45°} + 2, & |\beta| \in (0°, 90°\rangle \\ -\dfrac{\beta}{90°} + 0{,}5, & |\beta| \in (90°, 135°\rangle \end{cases} \quad \text{(S5)}$$

For the I, III and IV parts of the coordinate system, $f(\beta)$ takes values in the interval $(0,-2\rangle$, and as $|\beta|$ approaches 135° the values decrease. For points in parts I and IV of the system, Mk decreases at a rate of about 0.011 ($\frac{1}{90}$) per 1° of deviation, meaning that Mk takes on values in the interval $\langle -1.0)$ for them. For the points in part III, it decreases at a rate twice as high (about 0.022 ($\frac{1}{45}$) per 1° of deviation), which means that Mk values belonging to the interval $\langle -2,-1)$. The purpose of this scale decomposition was to determine, by means of a sign, whether a site was developing according to the assumptions of sustainable intensification. Only if these are met, the value of the directional indicator is positive. Another characteristic of Mk is its discontinuity. It does not take values in the interval $\langle 0,1)$. This is related to the fact that the II part of the system contains units whose indexes of socio-economic and environmental productivity were improving. If the value of Mk assigned to them were less than one, then the units would be "punished" as the SI index would be reduced by a fractional directional multiplier. However, fractions occur in parts I and IV of the system. The directional multiplier then takes a value in the interval $\langle -1,0)$. The points in these parts represent countries where the productivity index has improved in only one of the dimensions. Given that the directional multiplier appears with a negative sign in these parts of the system, it is reasonable to limit the negative effect of the multiplier by introducing its fractional values. This distinguishes parts I and III of the system from the part IV, where there is a deterioration of both performance indicators. Consequently, the directional multiplier takes the value $(-1,-2\rangle$. Finally, the sustainable intensification index is calculated as:

$$SI_a = Mk_a \times d(x_a, y_a) \quad \text{(S6)}$$

Kernel regression. Kernel regression is a way to nonparametrically estimate a conditional mean. Nonparametrically means that the parameter of interest, the mean as a function of the covariates, is given by the unknown function, which is an element of an infinite-dimensional space of functions. The regression model of outcome y_i given the k-dimensional vector of covariates x_i is given by:

$$\begin{aligned} y_i &= g(x_i) + \varepsilon_i \\ E(\varepsilon_i \mid x_i) &= 0 \end{aligned} \quad \text{(S7)}$$

where: ε_i – error term.

The covariates may include discrete and continuous variables. Implication of the above equations is that

$$E(y_i \mid x_i) = g(x_i) \quad \text{(S8)}$$

When we account for the information in the covariates, the error term provides no information about the mean of our outcome. The conditional mean function is therefore given by $g(x_i)$. By estimating $E(y_i \mid x_i = x)$ for all points x in our data, we obtain an estimate of $E(y_i \mid x_i)$. In this work we estimated local-linear regression, which estimates a regression for a subset of observations for each point in our data. Local-linear regression, for each point x, solves the minimization problem given by

$$\min\gamma \sum_{i=1}^{n} \left\{ y_i - \gamma_0 - \gamma_1^{'}(x_i - x) \right\}^2 K(x_i, x, h) \quad \text{(S9)}$$

where: $\gamma = (\gamma_0, \gamma_1^{'})^{'}$

This equation and its solution are similar to parametric ordinary least squares. The slope and the constant, however, have a different interpretation. The constant in, γ_0, is the conditional mean at a specific point x. The slope parameter, γ_1, is the derivative of the mean function with respect to x. The solution to this least-squares problem gives us the mean function and its derivative for each one of the elements of x. Repeating this optimization for each point x gives us the entire mean function and its derivatives.

Another difference between this approach and the minimization problem of parametric ordinary least squares is how the optimization is weighted. The weights are given by the kernel function $K(x_i, x, h)$. The kernel function assigns weights to observations x_i based on how much they differ from x and based on the bandwidth, h. The smaller h is, the larger the weight assigned to points between x_i and x. The bandwidth also determines the bias and variance of the mean function estimator.

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We selected the bandwidth using cross-validation, as suggested by Li and Racine (2004), which minimise the trade-off between bias and variance. For continuous variables we used Epanechnikov kernel function and for discreet variables Li–Racine kernel function was applied. Standard errors for variables were computed using bootstrap procedure with 50 replications. More information about the kernel regression procedure applied in this work can be found in Stata Manual (StataCorp 2021).

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Variables description

Table S1. Variables used in the study

Variable name	Description	Justification
Economic output		
OUTPUT	Total output (SE131) – Total of output of crops and crop products, livestock and livestock products and of other output. Sales and use of (crop and livestock) products and livestock + change in stocks of products (crop and livestock) + change in valuation of livestock – purchases of livestock + various non-exceptional products, expressed in EUR from 2010	Coluccia et al. (2020)
Economic inputs		
LAND	Total Utilised Agricultural Area (SE025) - Total utilised agricultural area of holding in ha (10 000 m2)	Skevas and Serra (2016)
LABOUR	Labour input (SE011) - Total labour input expressed in hours	Berre et al. (2015)
CAPITAL	Sum of Total intermediate consumption (SE275) – Total specific costs (including inputs produced on the holding) and overheads arising from production in the accounting year and Depreciation (SE360) – Entry in the accounts of depreciation of capital assets over the accounting year. It is determined on the basis of the replacement value. Concerns plantations of permanent crops, farm buildings and fixed equipment, land improvements, machinery and equipment and forest plantations. There is no depreciation of land and circulating capital. Expressed in EUR from 2010	Adenuga et al. (2020)
Socio-economic output		
GAP	Income gap – value of Farm Net Value added per Annual Working Unit (SE425) in EUR, related to Net earnings of single person without children earning 100% of the average earning, values for an average representative farm in the region, compared to average earning in the country, in EUR	Vitunskiene and Dabkiene (2016)
Environmental input		
CEREALS	Cereals share (SE035/SE025) - share of cereals in the utilised agricultural area (%)	Kołoszko-Chomentowska et al. (2015)
STOCKING	Stocking density (SE120) - density of ruminant grazing livestock per hectare of forage UAA	Cisilino et al. (2019)
FERT	Fertiliser material pressure (SE295/SE026) – cost of purchasing mineral fertilisers per ha of arable land	Martinho (2020)
PEST	Pesticides material pressure (SE300/SE026) – cost of purchasing pesticides per ha of arable land	Uthes et al. (2019)
Structural factors		
UAA_S	distribution of Utilised Agricultural Area (SE025) among farms of different economic size (SIZC) with standard concentration index C	Staniszewski and Kryszak (2020)
O_S	distribution of Total output (SE131) among farms of different economic size (SIZC) measured with standard concentration index C	
LAB_S	distribution of Labour input (SE011) among farms of different economic size (SIZC) measured with standard concentration index C	
LSU_S	distribution of Total livestock units (SE080) among farms of different economic size (SIZC) measured with standard concentration index C	

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Table S1. to be continued

Variable name	Description	Justification
Structural factors (continued)		
MIXED	share of output generated by non-specialised farms (60,70,80) in total output	Sintor et al. (2019)
UAA_TYPE	distribution of Utilised Agricultural Area (SE025) among farms of different production type (TF14) measured with Hirschman-Herfindahl Index	Staniszewski et al. (2023)
LAB_TYPE	distribution of Labour input (SE011) among farms of different production type (TF14) measured with Hirschman-Herfindahl Index	
LSU_TYPE	distribution of Total livestock units (SE080) among farms of different production type (TF14) measured with Hirschman-Herfindahl Index	
ABS_SPEC	distribution of Total output (SE131) among farms of different production type (TF14) measured with Hirschman-Herfindahl Index	
REL_SPEC	distribution of Total output (SE131) among farms of different production type (TF14) measured in relation to average value with Krugman Index	
ANIMAL	share of Total output livestock and livestock products (SE206) in Total output (SE131)	
Weather factors		
GDD	growing degree days - sum of celsusius degrees for temperatures above 5.5 degree in the growing season (March 1–Oct 31)	Spinoni et al. (2015)
HDD	heat degree days - sum of Celsius degrees for temperatures above 30 °C in the growing season (March 1–Oct 31)	Huffman et al. (2018)
PREC	precipitation - sum of precipitation (in mm) in the growing season (March 1–Oct 31)	Chambers and Pieralli (2020)
CWB	climate water balance - sum of precipitation (in mm) in the growing season (01.03-31.10) minus sum of evapotranspiration (March 1–Oct 31)	AGRI4CAST Resources Portal (2020)
RADIATION	radiation - average daily radiation in KJ/m2 in the growing season (March 1–Oct 31)	
VPD	vapor pressure deficit - the difference between how much water the air can hold when it is saturated and how much water it currently holds, value based on the difference between min and max temperature, average for the growing season	Roberts et al. (2013)
Control variables		
LAB_UAA	labour (SE011)/land (SE025) ratio	Martinsson and Hansson (2021)
CAP_UAA	capital (SE275+SE360)/land (SE025) ratio	
CAP_LAB	capital (SE275+SE360)/labour (SE011) ratio	Czyżewski et al. (2021)
HIRED_LAB	share of paid labour input (1–SE016) in Labour input (SE011)	Heidenreich (2022)
RENTED_LAND	share of rented U.A.A. (SE030) to total U.A.A. (SE025)	Eder et al. (2021)
DEBT	liabilities (SE485) to assets (SE436) ratio	Areal et al. (2018)
SUBSIDIES	ratio of Total subsidies - excluding on investments (SE605) to Total output (SE131)	Godoy-Durán et al. (2017)

U.A.A. – utilised agricultural area
Source: own study

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Measures of the structures. Concentration measures are presented in the form of Standard Concentration Index, which is a generalised version of well-known Gini index. For interval scale data, the following formula was used (Fuller and Lury 1977):

$$C = (p_1L_2 - p_2L_1) + (p_2L_3 - p_3L_2) + \dots + (p_{T-1}L_T - p_TL_{T-1}) \quad \text{(S10)}$$

where: $t = 1, \dots T$– subsequent intervals; p_t – cumulative share of the interval t in the ordering unit (farm size); L_t – the cumulative share of the interval t in the unit, which distribution is under study.

Specialisation measures are Hirschman-Hirfindahl indices, calculated according to the formula (Palan 2010, p. 15):

$$HHI = \sqrt{\sum_{i=1}^{I} b_i^2} \quad \text{(S11)}$$

where: I – analysed directions of agricultural production; b_i – share of the i-th direction of production in the structure.

Relative specialisation was estimated using the following equation for Krugman index (Palan 2010, p. 21):

$$K = \sum_{i=1}^{I} \left| b_i - \overline{b_i} \right| \quad \text{(S12)}$$

where: b_i – share of the i-th production type in the structure for the region; $\overline{b_i}$ – average share of the i-th production type in the structure for the whole sample.

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SI indicator.

Table S2. Mean SI indicators for the regions

Code	Name	*ECON-SOC EFF*	*ECON-SOC TFP*	*ENV EFF*	*ENV TFP*	*Mk*	d(x_n, y_n)	SI_a
15	Schleswig-Holstein Hamburg	0.7529	1.3313	0.1864	1.6666	1.333	0.8606	1.5637
30	Niedersachsen	0.7639	1.3143	0.177	1.6486	1.2997	0.8129	1.4685
50	Nordrhein-Westfalen	0.7136	1.2599	0.1549	1.6102	1.3681	0.7335	1.3542
60	Hessen	0.5667	1.3267	0.1416	1.6836	1.6228	0.828	1.5993
70	Rheinland-Pfalz	0.5181	1.3409	0.159	1.6194	1.5374	0.7852	1.4912
80	Baden-Wurttemberg	0.5546	1.3094	0.1311	1.5646	1.3313	0.7243	1.3604
90	Bayern	0.5644	1.4082	0.0969	1.659	1.6565	0.8638	1.6293
112	Brandenburg	0.6127	1.3076	0.7563	2.0066	1.0722	1.1903	1.6831
113	Mecklenburg-Vorpommern	0.7497	1.2549	0.8059	1.3821	1.0188	0.5982	0.9165
114	Sachsen	0.6256	1.3246	0.5557	1.6754	1.324	0.8404	1.5012
115	Sachsen-Anhalt	0.7469	1.3539	0.7514	1.7452	1.2385	0.9411	1.6
116	Thuringen	0.6535	1.347	0.9255	1.5631	1.0388	0.7614	1.1426
121	Ile De France	0.8345	1.3303	0.1733	1.4562	1.2298	0.6374	1.0544
131	Champagne-Ardenne	0.9501	1.0897	0.2066	1.2544	1.1811	0.3273	0.5167
132	Picardie	0.8909	1.1886	0.1554	1.4399	1.1296	0.5403	0.9273
133	Haute Normandie	0.8182	1.22	0.1654	1.5483	1.2761	0.6767	1.23
134	Centre	0.7593	1.3054	0.1698	1.5221	1.4449	0.6623	1.1932
135	Basse Normandie	0.7422	1.1849	0.1653	1.5117	1.2831	0.6006	1.1216
136	Bourgogne	0.7092	1.2698	0.183	1.5841	1.9016	0.6916	1.3354
141	Nord Pasde Calais	0.7827	1.1532	0.1269	1.4885	1.3862	0.5538	1.0305
151	Lorraine	0.7259	1.2145	0.1806	1.4706	1.3722	0.561	1.0531
152	Alsace	0.7151	1.1319	0.1333	1.3737	1.4154	0.4282	0.7959
153	Franche Comte	0.707	1.1579	0.2057	1.4855	1.2813	0.5868	1.1057
162	Pays de la Loire	0.7561	1.2446	0.1983	1.6899	1.7977	0.7817	1.4779
163	Bretagne	0.8256	1.193	0.2006	1.4838	1.7238	0.5529	1.0262
164	Poitou Charentes	0.7759	1.3079	0.158	1.7289	1.9088	0.8432	1.6002
182	Aquitaine	0.6355	1.1795	0.158	1.3253	1.217	0.4111	0.7582
183	Midi-pyrenees	0.5579	1.2135	0.1233	1.3958	1.6415	0.4773	0.9205
184	Limousin	0.4858	1.1706	0.1072	1.4102	1.7593	0.4671	0.8768
192	Rhone Alpes	0.6044	1.2375	0.1765	1.4268	1.7956	0.5126	0.9795
193	Auvergne	0.5485	1.26	0.1256	1.408	1.7853	0.5114	0.986
201	Languedoc Roussillon	0.5477	1.2114	0.2196	1.3397	1.2041	0.5011	0.8491
203	Provence Alpes Cote d'Azur	0.5765	1.2319	0.2418	1.5867	1.4956	0.6941	1.2936
204	Corse	0.5173	1.0754	0.2973	1.2519	0.6276	0.3476	0.5371
221	Valle d'Aosta	0.3126	1.4677	0.1436	1.2997	1.1343	0.7091	1.1152
222	Piemonte	0.4487	1.1654	0.0565	1.4833	1.0429	0.6315	1.0605
230	Lombardia	0.7758	1.1538	0.0708	1.0614	0.4965	0.2653	0.2346
241	Trentino	0.454	1.14	0.0628	0.8806	-0.301	0.2608	-0.046
242	Alto Adige	0.4715	1.1073	0.0754	0.9391	0.0052	0.2486	0.0305
243	Vento	0.5785	1.301	0.0343	1.0226	0.3321	0.4316	0.394
244	Friuli Venezia Giulia	0.5264	1.3612	0.0538	1.1511	0.6617	0.6548	0.8506

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Table S2. to be continued

Code	Name	*ECON-SOC EFF*	*ECON-SOC TFP*	*ENV EFF*	*ENV TFP*	*Mk*	d(x_n, y_n)	SI_a
250	Liguria	0.3585	1.7575	0.0626	1.3824	1.1292	1.0213	1.5999
260	Emilia Romagna	0.5518	1.2406	0.0592	1.0805	0.2813	0.4185	0.4487
270	Toscana	0.4064	1.0802	0.1003	1.3021	0.8601	0.4107	0.6094
281	Marche	0.3053	1.2336	0.0424	1.3088	1.376	0.4458	0.7916
282	Umbria	0.3396	1.3024	0.0503	1.294	1.4566	0.477	0.851
291	Lazio	0.3902	1.4131	0.0502	1.7857	1.6441	0.9735	1.7944
292	Abruzzo	0.2668	1.3563	0.044	1.5392	1.4524	0.7765	1.4357
301	Molise	0.2879	1.2721	0.0314	1.3797	1.5962	0.508	0.9486
302	Campania	0.3436	1.341	0.028	1.4589	1.0476	0.7043	1.3281
303	Calabria	0.2482	1.1463	0.0305	1.2898	0.9975	0.4253	0.5548
311	Puglia	0.3272	1.4905	0.038	2.3812	1.6846	1.6168	2.9263
312	Basilicata	0.2887	1.1687	0.0516	1.5368	1.2368	0.6238	1.0372
320	Sicilia	0.3444	1.2034	0.0479	1.468	0.9478	0.6549	1.1611
330	Sardegna	0.3469	1.0403	0.093	1.0421	0.0508	0.1845	0.1246
341	Vlaandren	0.6118	1.1688	0.1422	1.4978	1.6261	0.5792	1.0724
343	Wallonie	0.4931	1.1244	0.1071	1.3357	0.8521	0.4248	0.6435
350	Luxembourg	0.6209	1.1638	0.1689	1.4938	1.3291	0.5915	1.0699
360	Netherlands	0.8783	1.3071	0.2803	1.6241	1.8069	0.7207	1.3047
370	Denmark	0.9476	1.2196	0.242	2.0224	1.4676	1.1586	2.0856
380	Ireland	0.4109	1.6738	0.0643	1.8231	1.746	1.1832	2.2355
411	England North Region	0.6446	1.5922	0.2845	2.335	1.5109	1.6995	3.272
412	England East Region	0.6729	1.5776	0.3109	2.3108	1.5872	1.6133	3.1417
413	England West Region	0.5915	1.6585	0.2133	2.2479	1.4991	1.6094	3.1254
421	Wales	0.5307	1.6818	0.1585	2.1177	1.3955	1.5405	2.9243
431	Scotland	0.5357	1.6071	0.4131	1.9118	1.4236	1.3072	2.4232
441	Northern Ireland	0.4597	1.7579	0.1478	2.2176	1.4342	1.6651	3.2048
450	Makedonia Thraki	0.1926	1.1996	0.0095	3.083	1.3301	2.4809	3.9552
460	Ipiros Peloponissos NissiI	0.1816	1.3438	0.0159	1.7828	1.8231	0.9784	1.7685
470	Thessalia	0.1834	0.9854	0.0097	1.7627	0.3828	1.151	1.2833
500	Galicia	0.4079	1.1723	0.0526	1.1263	1.0912	0.2848	0.4103
505	Asturias	0.3273	1.5102	0.049	1.6438	1.8454	0.9027	1.6727
510	Cantabria	0.3821	1.053	0.0847	1.3517	1.0012	0.4786	0.5648
515	Pais Vasco	0.404	1.3548	0.0856	1.4611	1.6134	0.6453	1.1979
520	Navarra	0.5781	1.2214	0.0678	1.6871	1.9073	0.7698	1.4698
525	La Rioja	0.4333	1.144	0.0761	2.3861	1.0217	1.7767	2.3565
530	Aragon	0.4969	1.0995	0.0796	1.6938	1.1419	0.7791	1.2636
535	Cataluna	0.4391	1.0881	0.0592	1.9773	1.2295	1.1365	1.6642
540	Islas Baleares	0.3282	0.7901	0.0679	2.2167	-0.0884	1.4768	0.2912
545	Castilla Y Leon	0.47	1.118	0.0627	1.4296	1.02	0.5048	0.8259
550	Madrid	0.3065	0.8295	0.094	0.4502	-1.2873	0.5823	-0.8018
560	Comunidad Valenciana	0.3907	1.3642	0.0176	0.1532	-0.7232	0.8875	-0.6205
565	Murcia	0.4074	1.049	0.0524	0.7681	-0.4933	0.3491	-0.1807
570	Extremadura	0.3118	0.8261	0.1078	0.8332	-0.9732	0.2847	-0.4203

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Table S2. to be continued

Code	Name	*ECON-SOC EFF*	*ECON-SOC TFP*	*ENV EFF*	*ENV TFP*	*Mk*	d(x_n, y_n)	SI_a
575	Andalucia	0.3528	1.0107	0.0933	0.9193	-0.6114	0.3955	0.0488
615	Norte E Centro	0.1744	1.7253	0.0309	1.6678	1.7136	1.0822	2.0355
630	Ribatejo E Oeste	0.2748	1.5816	0.056	1.1702	0.9213	0.7464	0.9385
640	Alentejo E Algarve	0.2134	1.4011	0.0792	1.4172	1.6245	0.6824	1.2701
660	Austria	0.3685	1.3258	0.0845	1.3606	1.6379	0.5399	0.9925
670	Etela Suomi	0.4707	1.2413	0.0789	1.578	1.2464	0.7224	1.342
680	Sisa Suomi	0.4182	1.2802	0.0973	1.6437	1.3707	0.8397	1.528
690	Pohjanmaa	0.4867	1.3088	0.0889	1.4879	1.4159	0.671	1.2384
700	Pohjois Suomi	0.4153	1.4119	0.1239	1.9105	1.5342	1.149	2.1604
710	Slattbyggdslan	0.6573	1.3224	0.1797	1.654	1.4471	0.8451	1.6019
720	Skogsochmellanbygdslan	0.5816	1.3841	0.2067	1.4945	1.3511	0.7046	1.2956
730	Laninorra Sverige	0.4758	1.4318	0.2207	1.9738	1.6284	1.223	2.2699
740	Cyprus	0.2207	1.7942	0.0199	1.789	1.8824	1.1788	2.2455
745	Czechia	0.4089	1.1631	0.377	1.0021	0.5598	0.3003	0.2686
755	Estonia	0.3446	2.3684	0.1366	1.9174	1.7715	1.8352	3.24
764	Eszak Magyarorszag	0.3254	1.8439	0.0772	1.8886	1.4908	1.4079	2.6582
767	Alfold	0.3447	1.9217	0.0709	2.1387	1.6491	1.6875	3.2521
768	Dunantul	0.4	1.8177	0.0932	1.8711	1.4358	1.3599	2.484
770	Latvia	0.2315	2.4862	0.0784	1.9551	1.8054	1.9025	3.4081
775	Lithuania	0.1751	2.6145	0.0435	2.4746	1.9033	2.4315	4.6623
780	Malta	0.2363	1.3388	0.01	1.7204	1.4621	0.9016	1.6282
785	Pomorze i Mazury	0.2246	1.5446	0.0421	1.8834	1.613	1.138	2.1576
790	Wielkopolska i Slask	0.2136	1.4998	0.0271	1.7945	1.5877	1.0305	1.951
795	Mazowsze I Podlasie	0.1371	1.5042	0.0179	1.7769	1.5866	1.0184	1.9188
800	Malopolska i Pogorze	0.1108	1.4273	0.0157	1.8228	1.5427	1.0002	1.8027
810	Slovakia	0.3631	1.3964	0.8717	1.0694	0.7273	0.53	0.7258
820	Slovenia	0.181	2.2048	0.0271	1.5402	1.5616	1.4362	2.4306

ECON-SOC EFF – mean socio-economic efficiency; *ECON-SOC TFP* – geometric mean of socio-economic productivity; *ENV EFF* – mean of environmental efficiency; *ENV TFP* – geometric mean of environmental productivity; *Mk* – mean directional multiplier; $d(x_n, y_n)$ – mean Euclidean distance; *SI* – mean sustainable intensification index

Source: own study

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Variables clustering. To reduce the number of explanatory variables introduced into the model, cluster analysis was used. The rationale for this was to avoid excessive collinearity and duplication of variation of highly correlated factors. Factors were analysed in three separate groups: structural features, weather conditions and control variables. Clustering was conducted for the average values of variable for the whole analysed period. It was based on the Ward method and distance between variables was assessed basing on Pearson correlation. *P*-values for clusters were obtained through bootstrapping procedure using pvclust package in R (Suzuki et al. 2019). Results are presented in Figure S2 below. Variables description is available in Table S1.

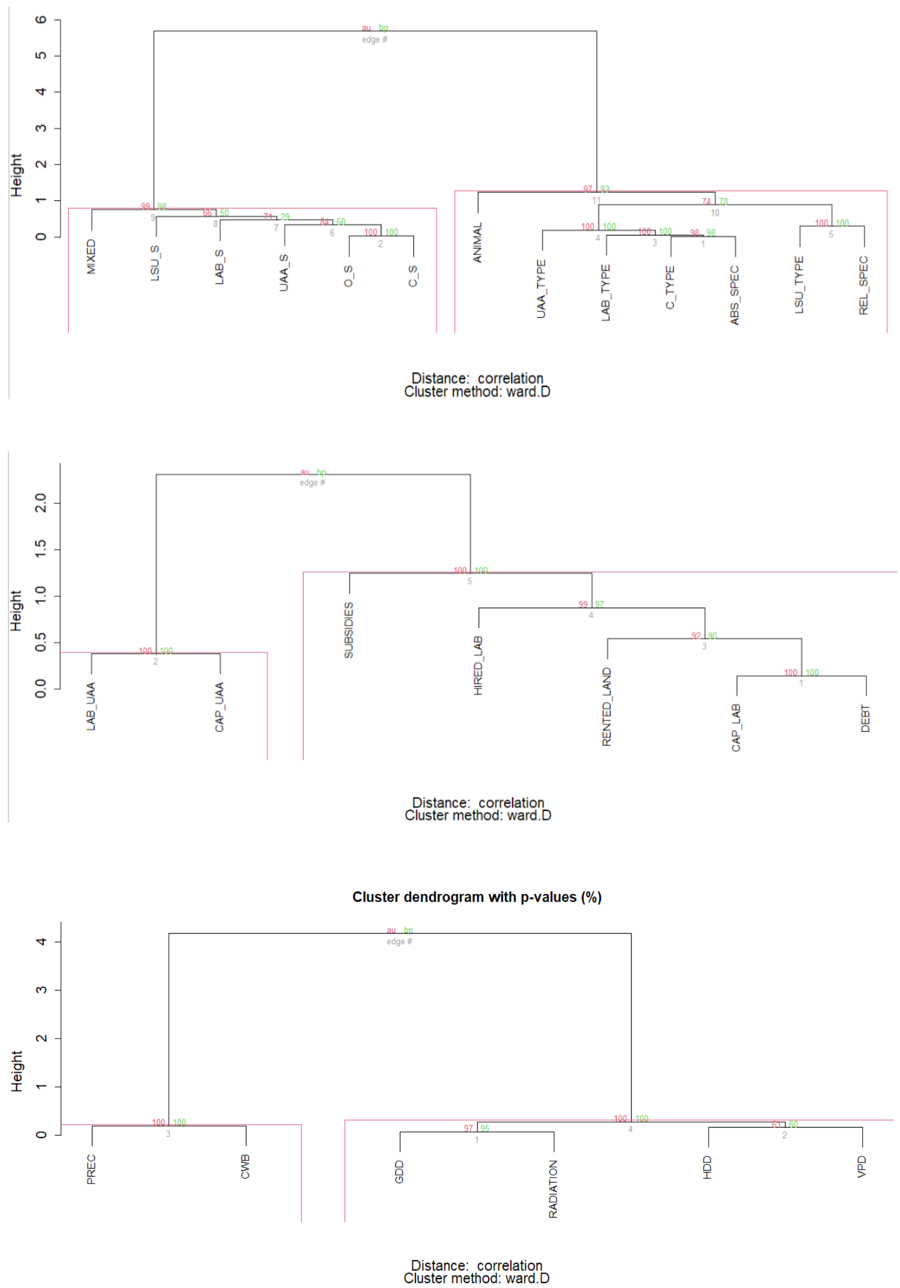

Figure S2. Results of variables clustering – dendrograms with *P*-values (%)

Source: own study

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Kernel regression results.

Table S3. Standard errors comparison for different number of bootstrap replications

Variable	Bootstrap replications = 50			Bootstrap replications = 400		
	bootstrap SE	percentile (95% conf. interval)		bootstrap SE	percentile (95% conf. interval)	
ABS_SPEC	0.168629	–1.00633	–0.34673	0.1669	–1.00805	–0.34997
LSU_S	0.236558	–1.01499	–0.15163	0.245972	–1.02487	–0.14726
UAA_S	0.521291	0.329439	2.417882	0.543779	0.361908	2.646094
RADIATION	0.000011	–0.00016	–0.00012	0.000013	–0.00017	–0.00011
RENTED_LAND	0.168203	–0.2514	0.37807	0.138292	–0.18985	0.343685
HIRED_LAB	0.178891	0.047206	0.70893	0.164704	–0.03054	0.610677

Specific variables description in Table S1.
Source: own study

Table S4. Effects bandwidth in kernel regression

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LSU_S	0.35	0.424	0.365	0.786	0.788	0.634	0.845	0.551	0.21
LAB_S	0.18	0.21	–	–	–	–	–	–	–
UAA_S	0.235	0.255	0.238	0.457	0.441	0.442	0.527	0.322	0.13
O_S	0.213	0.222	0.233	0.617	0.624	–	–	–	–
ABS_SPEC	0.394	0.487	0.381	0.882	–	0.664	1.05	0.561	0.226
REL_SPEC	0.21	0.234	0.222	0.36	–	–	–	–	–
MIXED	0.269	–	–	–	–	–	–	–	–
ANIMAL	0.369	–	–	–	–	–	–	–	–
PREC	–	–	–	572.68	580.66	–	–	–	–
RADIATION	–	–	–	12 993	13 175	8 884	14 533	8 356	3 359
CAP_UAA	–	–	–	–	–	–	7 563	–	–
SUBSIDIES	–	–	–	–	–	–	0.81	–	0.169
RENTED_LAND	–	–	–	–	–	–	–	0.721	–
HIRED_LAB	–	–	–	–	–	–	–	0.618	0.257

Specific variables description in Table S1.
Source: own study

https://doi.org/10.17221/235/2023-AGRICECON

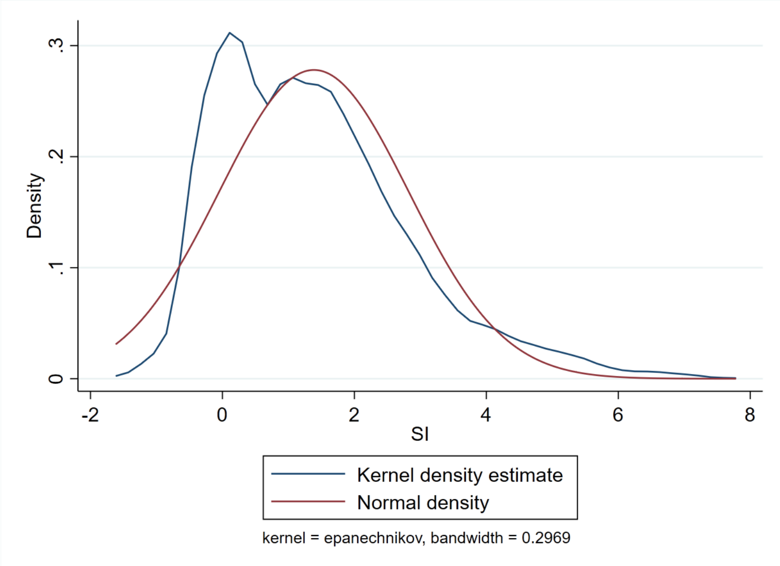

Figure S3. Distribution of sustainable intensification

Source: own study

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