Sustainable or not sustainable, that's the question: ranking European regional agricultural systems using Data Envelopment Analysis

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1.   Introduction

Sustainability is a complex and sophisticated concept. Measuring to what extent a complex regional agricultural system is sustainable is difficult and challenging. For example, in different decision-making contexts stakeholders can use different criteria and methodologies, thus arriving at different (and contrasting) judgments about the sustainability of the same agricultural practice (e.g. a certain amount of soil erosion per hectare could be judged as sustainable in the EU and not in the US, in China, or in Australia). Therefore in this paper we first discuss the concept of sustainability and then the way to operationalize it and to make it useful for assessment procedures using Data Envelopment Analysis (DEA) as methodological approach. The use of DEA for assessing sustainability is not new. Cherchye and Kuosmanen (2002; 2006), for example, discussed different applications of DEA for the assessment of sustainable development at country level. Other papers addressed this issue at firm and sector level and mainly focused on the concept of eco-efficiency (Zaim 2004; Kuosmanen and Kortelainen 2005; 2007). Lu and Lo (2007) used a DEA approach to rank 31 Chinese regions in terms of their sustainability taking into account economic and environmental indicators. In this paper we focus on a broader conceptualization of sustainability and we apply a DEA approach to assess European agricultural performances on a regional level. To our knowledge this is the first time a regional level dataset and DEA have been used in a paper to provide such an assessment. This level of analysis will become increasingly important in following years in order to support European decision making processes related to rural development policy. Our perspective is to consider the "mosaic approach" of sustainability and its three dimensions (Smith and McDonald, 1998; OECD, 2008): economic, social, and environmental. The mosaic approach of sustainability is related to the capacity of human activity (e.g. land management) (1) to be feasible (*economic dimension*), and (2) to be acceptable by society (*social dimension*), and (3) to maintain ecological processes (*environmental dimension*) (Tisdell 1997; Perman et al. 2003, p. 93). In this sense sustainable agriculture can be considered as a process in which demand for its products, such as food, raw materials and rural amenities, is met from farming practices that are economically efficient, socially acceptable, and environmentally friendly.

This paper is organized as follows: in Section 2 we present the indicators used to address the issue of measuring sustainability at regional level. In Section 3 we present the basic DEA models. In Section 4 we present the scenarios we implemented in order to address the different dimensions of sustainable development. In Section 5 we present the computational results. Finally in Section 6 concluding remarks are presented as well as directions for further research.

2.   Indicators of sustainability

The main problem when dealing with the assessment of sustainability is that this concept often appears as a "black box" in terms of usage. This is due to the fact that the concept of sustainability carries a variety of meanings, exemplified by the very different interpretations given to it by social and natural scientists (i.e. economists, sociologists, and ecologists). Hence for answering the question whether a given system (i.e. a region) is sustainable we often need reference levels, indicators, and benchmarking methods (Cherchye and Kuosmanen 2002; 2006). As highlighted by Oskam and Feng (2008) almost all definitions of sustainability make its identification and measurement problematic, because they are related to dynamicity and uncertainty. This means that the judgment on

87 sustainability is often scale, time and socially (institutionally) dependent, and
88 assessment of sustainability is complex. For example, it is highly unclear what
89 will be the future needs of society, and what will be the scale of values that will be
90 adopted. This explains why it is "easier" to express an evaluation on what is
91 *un*sustainable (now) rather than on what is sustainable (now and tomorrow)
92 (Oskam and Feng 2008). Therefore even though the theoretical definition of
93 sustainability is clear, it is less clear how to make it operational in an empirical
94 analysis. We use the mosaic approach to assess the sustainability of the
95 agricultural systems in the European regions. As stated in Section 1 the mosaic
96 approach states that the *economic dimension* requires feasibility, the *social*
97 *dimension* requires acceptability, and the *environmental dimension* requires
98 carrying capacity (Spangenberg 2002; Schleyer *et al*. 2007). Usually at country
99 (national) level this is addressed by using indices of sustainable development
100 linked to data collected by International Institutes. These data often are not
101 available at regional (sub-national) level. Examples are the Environmental
102 Sustainability Index of the World Economic Forum (WEF 2002), the Human
103 Development Index of the United Nations Development Program (UNDP 2001)
104 or the Ecological Footprint (Wackernagel *et al*. 2002). OECD has recently
105 provided useful national and regional-based indicators specifically oriented to
106 measure the sustainability of agriculture using the mosaic approach
107 conceptualization background (OECD 2008). At regional level also the European
108 Union has recently proposed suitable indicators of agricultural sustainability.
109 Among others the EU proposes economic indicators related to productivity and
110 investments, social indicators linked to the take-over ratio and the level of
111 education in agriculture, and environmental indicators related to soil erosion and
112 water use[1].
113 In Table 1 we present the indicators we selected from this dataset in order to
114 assess sustainability of agricultural systems at the level of European regions. We
115 selected these indicators in order to fulfill two basic concepts: closeness to the
116 theoretical definitions and availability of information for all the units of analysis
117 we are considering in this research. For addressing the economic dimension we
118 selected two indicators: productivity of labor and the gross fixed capital formation
119 in agriculture. They are linked to the idea of increasing the competitiveness and
120 efficiency of the European agriculture. Both are of the type more is better. For
121 addressing the social dimension we selected two indicators: ratio of farmers under
122 35 years of age to farmers over 55 years of age, and the level of training and
123 education in agriculture. They indicate the capacity of agriculture to provide
124 acceptable living conditions such that a good standard of education can be
125 achieved and future generations of land managers can procure an acceptable
126 standard of living. Both indicators give insights related to the capacity of
127 agriculture to promote social cohesion and equity. They are of the type more is
128 better. For addressing the environmental dimension we selected four indicators:
129 the risk of soil erosion, the intensity of plant production and animal grazing and
130 the relevance of irrigated areas. They are linked to the objective of reducing the
131 consumption of important natural resources such as soil and water, and to
132 enhancing resilience of agro-ecosystems. They are all of the type less is better.
133
134

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[1] http://ec.europa.eu/agriculture/agrista/rurdev2008/index_en.htm

135 **Table 1 – Indicators of sustainability of agriculture in European regions**

Indicators	Type
Economic dimension (feasibility)	
Productivity of labor	
1. Value added per AWU[a]	More is better
Investment level	
2. Gross Fixed Capital Formation in agriculture (euro/farm)	
Social dimension (acceptability)	
Inter-generational equity	
3. Ratio of farmers < 35 years / farmers ≥ 55 years	More is better
Education level	
4. Training and education in agriculture (% land managers with high education)	
Environmental dimension (carrying capacity)	
Land management	
5. Risk of soil erosion (t/(year·ha))	
6. Intensity of land use for plant production (%UAA)[b]	Less is better
7. Intensity of land use for animal production (%UAA)[b]	
Water management	
8. Relevance of irrigated areas (%UAA)[b]	

136 Source: Our elaboration on European Commission – Agriculture and Rural Development Dataset[1]
137 [a] where AWU means Annual Work Unit; [b] where UAA means Utilized Agricultural Area

138

139 A dataset for 252 regions in the European Regions (NUTS2) is established from
140 the European Commission – Agriculture and Rural Development Dataset for the
141 year 2004/5[2]. In Table 2 we present the summary statistics of the indicators of
142 sustainability for the regions.

143

144 **Table 2 – Summary statistics of the indicators of sustainability**

Indicators	Statistics			
	Mean	Max	Min	S.D.
Economic indicators				
1. Gross value added per AWU (10^3 euro/AWU)	23.53	77.22	1.09	14.93
2. Gross Fixed Capital Formation in agriculture (10^3 euro/farm)	12.06	63.8	0.00	12.36
Social indicators				
3. Ratio: farmers < 35 years / farmers ≥ 55 years	0.17	0.60	0.00	0.13
4. Training and education in agriculture (%)	35.91	89.70	0.40	24.05
Environmental indicators				
5. Risk of soil erosion (t/(year·ha))	1.55	31.79	0.00	3.27
6. Intensity of land use for plant production (%UAA)	79.94	100.00	0.51	28.05
7. Intensity of land use for animal production (%UAA)	92.09	100.00	0.00	20.81
8. Relevance of irrigated areas (%UAA)	5.59	60.43	0.00	10.11

145 Source: our elaboration on European Commission – Agriculture and Rural Development Dataset[1]

146

147 Economic indicator 1 is the gross value added at basic price per annual working
148 unit in agriculture. Gross value added is defined as the value of output less the
149 value of intermediate consumption. Output is valued at basic prices and
150 intermediate consumption is valued at purchasers' prices. As indicated by the
151 European Commission the gross value added per Annual Work Unit (AWU)
152 provides comparable data on labor productivity and allows for comparison over
153 sub-sectors and regions. An Annual Working Unit corresponds to 2,200 working
154 hour per year which is the amount of hours an employee is willing to provide
155 when fully employed in the agricultural business. Economic indicator 2 is the
156 gross fixed capital formation in agriculture per farm. It refers to the investments in
157 assets that are used repeatedly or continuously over a number of years to produce
158 goods in agriculture. Social indicator 3 refers to the ratio of young and old farmers
159 in a given region. It provides the measurement of the take-over in agriculture. A

[2] This year will be used by the EU Commission as the reference point (baseline) from which
starting to assess the effect of Rural Development Strategy in the EU in the period 2007-2013.

160 ratio close to zero indicates an extremely low take-over (therefore an unattractive
161 agricultural sector) while a value close to one indicates a high take-over (and
162 therefore a very attractive agricultural sector). Social indicator 4 refers to the
163 percentage of farmers who received a full agricultural training. This indicator is
164 calculated as any training course continuing for the equivalent of at least two
165 years full time training after the end of compulsory education and completed at an
166 agricultural college, university or other institute of higher education in agriculture,
167 horticulture, viticulture, sylviculture, pisciculture, veterinary science, agricultural
168 technology or an associated subject. Environmental indicator 5 refers to the risk of
169 soil erosion which is estimated on the base of the Pan-European Soil Erosion Risk
170 Assessment model – Pesera project (JRC-Ispra). This indicator expresses the
171 potentiality of soil loss in terms of ton per hectare and per year. Environmental
172 indicators 6 and 7 indicate the percentage of hectares under intensive agriculture.
173 Indicator 6 is the area under arable crops production (except forage crops), when
174 the regional yield for cereals (excluding rice) is more than 60% of the EU-27
175 average. Cereal yield is a 3 years average. Indicator 7 is the area for grazing
176 livestock production (cattle, sheep, and goats), when the stocking density exceeds
177 1 Livestock Unit per hectare of forage area (forage crops, permanent pastures and
178 meadows). Environmental indicator 8 refers to the relevance of irrigated areas
179 calculated as the percentage of hectares in which irrigation is used. An irrigated
180 area is defined as the area of irrigated crops, i.e. the area of crops that have
181 actually been irrigated at least once during the 12 months prior to the survey date.
182 Crops under glass and kitchen gardens, which are almost always irrigated, are not
183 included.
184
185 **3.   Basic models, Data Envelopment Analysis (DEA)**
186 Data Envelopment Analysis (DEA) was developed in 1978 by Charnes, Cooper
187 and Rhodes (Cooper *et al*. 1978) as a mathematical programming technique for
188 evaluating and comparing the performance of a set of decision making units
189 (DMU's) with common inputs and outputs. No a priori weights are needed. DEA
190 indicates a set of best performers, i.e. the most efficient units from the total set,
191 having an efficiency level of 1. DEA also calculates the efficiency levels of the
192 remaining DMU's, which are values between 0 and 1. In the domain of
193 sustainable development assessment DEA approaches have been developed by
194 several authors, for example to address differences among countries in terms of
195 sustainable development (Cherchye and Kuosmanen 2002; 2006), or to measure
196 the eco-efficiency of private firms (Zaim 2004; Kuosmanen and Kortelainen
197 2005; 2007). An application of DEA at regional level could be found in Lu and Lo
198 (2007) referring to the assessment of sustainable development of 31 Chinese
199 regions. In the context of this paper our DMU is a European region and the type
200 of performance we are looking for is the sustainability of the regional agricultural
201 system. To use a region as DMU is consistent to the type of decision making
202 process we are experiencing in the European Union in relation to the organization
203 and the implementation of the rural development policies. This level of decision
204 making will become even more and more important in the near future in order to
205 address the linkages between sustainability and rural development in the European
206 Union (Buckwell 2010).
207 Within the DEA framework a DMU is defined as an entity that converts inputs
208 into outputs. It is assumed that the set under investigation consists of R units
209 (DMU$_1$, DMU$_2$, …, DMU$_R$). Each unit consumes I inputs to produce J outputs. A
210 certain unit DMU$_r$ consumes input i in a quantity of x_{ir} and produces output j in a

211 quantity of y_{jr} ($x_{ir} \geq 0$ and $y_{jr} \geq 0$ for all i, j, r). Efficiency is defined as ratio of the
212 weighted sum of the outputs and the weighted sum of the inputs, under the
213 restriction that efficiency can never exceed the value of 1. The efficiency of a
214 DMU increases as its outputs increase and/or its inputs decrease (and vice versa).
215 In this study 252 European regions are modeled as the DMU's, the indicators of
216 the type "less is better" are modeled as the inputs (environmental indicators), and
217 the indicators of the type "more is better" are modeled as the outputs (economic
218 and social indicators). One by one each region is chosen as the reference region. A
219 model is formulated in which the weights that the reference region assigns to the
220 various inputs and outputs are the decision variables. These weights are chosen in
221 such a way that the efficiency of the reference region is maximized:

222
$$\max \sum_{j=1}^{J} y_{j0} U_j \tag{1}$$

223 s.t.
$$\sum_{i=1}^{I} x_{i0} V_i = 1 \tag{2}$$

224
$$\sum_{i=1}^{I} x_{ir} V_i \geq \sum_{j=1}^{J} y_{jr} U_j \qquad \text{for } r = 1...R \tag{3}$$

225 $\quad V_i \geq 0$ for $i = 1...I$ $\hphantom{xxxxxxxxxxxxxxxxxxxxxxxx}$ (4)
226 $\quad U_j \geq 0$ for $j = 1...J$ $\hphantom{xxxxxxxxxxxxxxxxxxxxxxxx}$ (5)
227

228 with $r = 0$ the reference region, U_j the non-negative weight that the reference
229 region assigns to output j, V_i the non-negative weight that the reference region
230 assigns to input i. Objective function (1) maximizes the weighted sum of the
231 outputs of the reference region. Restriction (2) states that the weighted sum of the
232 inputs of the reference region should equal 1. As the efficiency of the reference
233 region is defined as the ratio of the weighted sum of its outputs and the weighted
234 sum of its inputs the objective function (1) equals the efficiency of the reference
235 region. Restriction (3) assures that the efficiency of each of the regions is no more
236 than 1. In order to measure the efficiency of R different regions the model has to
237 be run R times.
238 According to model (1)-(5) each region will set the weights in such a way that its
239 own efficiency is maximized, which implies that (a) the weights assigned to the
240 inputs and outputs can differ greatly from one region to another, (b) every region
241 has the opportunity to "ignore" (i.e. assign zero weight to) inputs and outputs for
242 which its indicators are relatively bad. Following Pedraja-Chaparro *et al.* (1997)
243 we formulated restrictions that put lower bounds (6,8) and upper bounds (7,9) on
244 the relative weight that the reference region can assign to inputs and outputs:

245
$$y_{j0} U_j \geq u\_low \sum_{k=1}^{K} y_{k0} U_k \qquad \text{for } j = 1...J \tag{6}$$

246
$$y_{j0} U_j \leq u\_up \sum_{k=1}^{K} y_{k0} U_k \qquad \text{for } j = 1...J \tag{7}$$

247 $\quad x_{i0} V_i \geq v\_low$ $\hphantom{xxxxxxxxxxxx}$ for $i = 1...I$ $\hphantom{xxxxxxxx}$ (8)
248 $\quad x_{i0} V_i \leq v\_up$ $\hphantom{xxxxxxxxxxxx}$ for $i = 1...I$ $\hphantom{xxxxxxxx}$ (9)

249 with u_low (v_low) the lower bound of the relative weight of each output (input),
250 and u_up (v_up) the upper bound of the relative weight of each output (input).
251
252 **4.   Scenarios**

253 By using the model set-up we presented in the previous section we are able to
254 transfer the conceptual background of the mosaic approach of regional
255 agricultural sustainability into an appropriate operational decision making
256 framework. Regions with the best performance in (at least) one of the dimensions
257 of sustainability will have high efficiencies.

258 *Scenarios*

259 The model set-up allows us to experiment with various preferences for the
260 importance of each of the three dimensions in assessing the sustainability of the
261 regions. Accordingly five scenarios were used for ranking the regions based on
262 the efficiency that results from their indicators of sustainability:

263   A. *Basic scenario* – Standard DEA model.
264   B. *Balanced scenario* – Lower bounds and upper bounds on the relative
265   weights of all inputs and outputs.
266   C. *Economic scenario* – A lower bound is put on the relative weights of the
267   economic indicators.
268   D. *Social scenario* – A lower bound is put on the relative weights of the
269   social indicators.
270   E. *Environmental scenario* – The ranking is based solely on the values of the
271   environmental indicators.

272 The properties and characteristics of each scenario can be summarized as follows:

273 *A. Basic scenario:* This scenario models an assessment procedure where regions
274 are ranked without assuming any preferences with respect to the dimensions of
275 sustainability. The efficiencies of all regions were calculated by running basic
276 DEA-model (1)-(5) for every region. Then the European regions were ranked
277 according to their efficiencies.

278 *B. Balanced scenario:* This scenario models an assessment procedure where all
279 three dimensions of sustainability are taken into account. Regions should use all
280 outputs and inputs when they optimize their efficiency, and they should not assign
281 more than 50% relative weight to one input or one output. Therefore restrictions
282 (6B), (7B), (8B), and (9B) were added to model (1)-(5):

283
$$y_{j0}U_j \geq \tfrac{1}{10}\sum_{k=1}^{K} y_{k0}U_k \qquad\qquad \text{for } j = 1\ldots J \qquad\qquad (6B)$$

284
$$y_{j0}U_j \leq \tfrac{1}{2}\sum_{k=1}^{K} y_{k0}U_k \qquad\qquad \text{for } j = 1\ldots J \qquad\qquad (7B)$$

285 $\quad x_{i0}V_i \geq \tfrac{1}{10} \qquad\qquad\qquad\qquad\qquad \text{for } i = 1\ldots I \qquad\qquad (8B)$

286 $\quad x_{i0}V_i \leq \tfrac{1}{2} \qquad\qquad\qquad\qquad\qquad\quad \text{for } i = 1\ldots I \qquad\qquad (9B)$

287 *C. Economic scenario:* This scenario models an assessment procedure where the
288 economic dimension is regarded as the most important one. The relative weight
289 that the reference region assigns to the economic indicators 1 (labour
290 productivity) and 2 (fixed capital formation in agriculture) should be at least three
291 times higher than the relative weight assigned to the social indicators. This was
292 modelled by adding restriction (6C) to model (1)-(5):

293
$$y_{10}U_1 + y_{20}U_2 \geq \tfrac{3}{4}\sum_{k=1}^{K} y_{k0}U_k \qquad\qquad (6C)$$

294 *D. Social scenario:* This scenario models an assessment procedure where the
295 social dimension is regarded as the most important one. The relative weight that
296 the reference region assigns to the social indicators 3 (ratio farmers < 35 years /
297 farmers ≥ 55 years) and 4 (training and education in agriculture) should be at least

7

298 three times higher than the relative weight assigned to the economic indicators.
299 This was modelled by adding restriction (6D) to model (1)-(5):

300
$$y_{30}U_3 + y_{40}U_4 \geq \tfrac{3}{4} \sum_{k=1}^{K} y_{k0}U_k \qquad (6D)$$

301 *E. Environmental scenario:* This scenario models an assessment procedure where
302 only the environmental dimension is considered. Therefore it was assumed that all
303 regions have only 1 output, for which they all have the same value. So economic
304 and social indicators 1-4 were removed from the model, and replaced with
305 (artificial) indicator 9, for which all regions have value 1. Regions should use all
306 inputs while optimizing their efficiency. Model (1)-(5) is changed accordingly:
307
308 $\qquad \max \quad U_9 \qquad\qquad\qquad\qquad\qquad\qquad\qquad (1E)$

309 s.t. $\quad \displaystyle\sum_{i=1}^{I} x_{i0} V_i = 1 \qquad\qquad\qquad\qquad\qquad (2)$

310 $\qquad\quad \displaystyle\sum_{i=1}^{I} x_{ir} V_i \;\geq\; U_9 \qquad\qquad\qquad\qquad (3E)$

311 $\qquad\quad V_i \geq 0 \qquad\qquad\qquad\qquad$ for $i = 1\ldots I \qquad (4)$
312 $\qquad\quad U_9 \geq 0 \qquad\qquad\qquad\qquad$ $\qquad\qquad\quad (5E)$
313 $\qquad\quad x_{i0} V_i \geq \tfrac{1}{10} \qquad\qquad\qquad$ for $i = 1\ldots I \qquad (8E)$
314 $\qquad\quad x_{i0} V_i \leq \tfrac{1}{2} \qquad\qquad\qquad$ for $i = 1\ldots I \qquad (9E)$

315
316 **5.   Computational results**
317 In Appendix 1 we present the efficiencies of 252 European agricultural regions as
318 calculated under the five different scenarios[3]. Given the size of the sample we
319 comment these efficiencies (i) first sketching the information about the most
320 efficient regions in basic scenario A, and (ii) secondly synthesizing results per
321 scenario and per country.
322 (i) In basic scenario A, where we run a free optimization model, 35 European
323 regions have efficiency 1. As the models of scenarios B, C, and D are defined by
324 adding extra restrictions to the model of scenario A no region can have a higher
325 efficiency under scenario B, C, or D than under scenario A. So all regions that are
326 efficient under scenario B, C, or D are also efficient under basic scenario A.
327 Environmental scenario E uses a different set of outputs than scenario A.
328 Therefore a region can have a higher efficiency in scenario E than in scenario A.
329 Adding balancing constraints (6B), (7B), (8B), (9B) in scenario B has quite an
330 impact on the number of efficient regions: only 11 regions are efficient in
331 balanced scenario B. It turns out that 23 regions are efficient in economic scenario
332 C, and that 27 regions are efficient in social scenario D, and that 7 regions are
333 efficient in environmental scenario E. In Table 3 we present the efficiencies of the
334 35 regions that are efficient in basic scenario A, given per country and per
335 scenario. The efficient Spanish, Italian and Swedish regions owe their efficiency
336 to the economic dimension while German, Dutch, and British regions owe their
337 efficiency mainly to both the social and the economic dimension. The efficient
338 Austrian and Finnish regions present more balanced performances while the
339 efficient Polish regions owe their efficiency mainly to the values of their social

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3 Appendix 1 couldn't be included in this version of the paper due to the limited number of pages available. The interested
reader is welcome to request it to the authors.

340 indicators. There are 6 regions that show maximum efficiency in all five
341 scenarios: the Austrian Salzburg, Tirol and Vorarlberg, Hamburg in Germany,
342 Åland in Finland and the UK Highlands & Islands. They seem to show the
343 "perfect" combination of low natural resource use (i.e. land and water) and high
344 socio-economic performance. Hamburg and Salzburg are prevailing urban regions
345 while all the others are intermediate (Vorarlberg) or prevailing rural regions[4]. (ii)
346 A second approach we use to analyse results is to organize information of the
347 overall regional performances per country such that variability within and
348 between countries can be detected. Appendix 2 shows the main descriptive
349 statistics for each EU State Member in each scenario[5]. In basic scenario A the best
350 performers are Finland, Germany, and The Netherlands (0.930, 0.910, and 0.890
351 respectively) while the poorest performers are Slovakia (0.123), Cyprus (0.146),
352 Greece (0.179), Bulgaria (0.182), Malta (0.186), Hungary (0.196), and Romania
353 (0.197). The best performers in the balanced scenario B are again Finland,
354 Germany, and The Netherlands (0.881, 0.735, and 0.690 respectively), while
355 poorest performers are again Malta (0.013), Bulgaria (0.031), Romania (0.044),
356 Slovakia (0.045). In economic scenario C The Netherlands and Finland present
357 high scores again (0.857 and 0.819 respectively) while Bulgaria (0.044), Lithuania
358 (0.058), Slovakia (0.079), Hungary (0.090), and Romania (0.098) have the lowest
359 scores. In social scenario D besides Finland (0.930), Germany (0.910), and The
360 Netherlands (0.855) also Czech Republic presents a relatively high score (0.829).
361 Poorest performers in this case are Slovakia (0.122), Cyprus (0.129),
362 Portugal(0.138), Greece (0.165), Spain (0.169), Italy (0.177), Malta (0.178), and
363 Bulgaria (0.182). A different ranking is found in environmental scenario E.
364 Estonia (1.000), Latvia (0.973), and Finland (0.870) have the highest efficiencies
365 while Denmark (0.290), Malta (0.300), Cyprus (0.306), and Greece (0.307) have
366 relatively low efficiencies.
367 In general the Central and Northern European regions show higher efficiencies
368 than both the Southern (Mediterranean) and the "new Member State" (i.e. former
369 communist countries) regions. Only in social scenario D former communist
370 countries perform relatively well, while Mediterranean regions still show poor
371 performances. These results are in line with the main observations of the current
372 researches on development divergences of the European regions (Crescenzi,
373 2009). Besides evaluating the European countries in terms of their average
374 efficiencies in the different scenarios it is also interesting to look at the variability
375 in different countries. For comparing the variabilities we use the standard
376 deviations as presented in Appendix 2. Poland, Sweden, and Austria have the
377 highest standard deviations in basic scenario A. Under balanced scenario B
378 Austria, UK, and Czech Republic have the highest standard deviations. In
379 economic scenario C again Austria has the highest standard deviation, followed

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[4] The EU Commission classified the European regions accordingly to the OECD methodology. This methodology is based on population density (OECD, Creating rural indicators for shaping territorial policy, Paris, 1994). It is based on a two-step approach: First, the OECD identifies local areas (municipalities) as rural if the population density is below 150 inhabitants per square kilometer. Then, at regional level (NUTS 3 or NUTS 2), the OECD distinguishes:
- Predominantly Rural regions (PR) : more than 50% of the population is living in rural communes (with less than 150 inhabitants / km^2)
- Intermediate Regions (IR) : 15% to 50% of the population of the region is living in rural local units
- Predominantly Urban regions (PU) : less than 15% of the population of the region is living in rural local units

As a result, the regions (NUTS 3 or NUTS 2) can be 'flagged' with their category: Predominantly Rural, Intermediate, Predominantly Urban. Characterization of the rural character at regional level, where most of the statistics are available, allows drawing easily a picture of the different types of areas at national level.

[5] Appendix 2 couldn't be included in this version of the paper due to the limited number of pages available. The interested reader is welcome to request it to the authors.

380 by Sweden and Czech Republic. Poland, Austria, and Czech Republic have the
381 highest standard deviations in social scenario D. Austria is also the country with
382 the highest standard deviation in environmental scenario E. Appendix 2 also
383 shows the minimum and the maximum efficiency per country. It can be seen that
384 in most countries the difference between the most efficient region and the least
385 efficient region is considerable.
386

387 **Table 3 – Efficiency scores of the 35 European regions (in scenario A).**

Country	Region code and name		A Free	B Balanced	C Economic	D Social	E Environmental
					Scenario		
Austria	AT32	Salzburg	1	1	1	1	1
	AT33	Tirol	1	1	1	1	1
	AT34	Vorarlberg	1	1	1	1	1
Germany	DE13	Freiburg	1	0.720	0.438	1	0.740
	DE23	Oberpfalz	1	0.679	0.382	1	0.676
	DE41	Brandenburg-NO	1	1	1	1	0.720
	DE42	Brandenburg-SW	1	0.914	0.898	1	0.723
	DE60	Hamburg	1	1	1	1	1
	DE80	Mecklenburg	1	1	1	1	0.680
	DE94	Weser-Ems	1	0.991	0.838	1	0.699
	DEA1	Düsseldorf	1	0.715	0.665	1	0.669
	DEC0	Saarland	1	0.801	0.553	1	0.751
	DED3	Leipzig	1	0.916	0.864	1	0.661
	DEE1	Dessau	1	0.983	1	1	0.685
	DEE2	Halle	1	1	1	1	0.668
	DEE3	Magdeburg	1	0.938	0.932	1	0.677
Spain	ES13	Cantabria	1	0.258	1	0.361	0.709
Finland	FI13	Itä-Suomi	1	0.883	0.717	1	0.929
	FI1A	Pohjois-Suomi	1	1	1	1	0.830
	FI20	Åland	1	1	1	1	1
Italy	ITD1	Provincia Bolzano	1	0.617	1	0.695	0.532
	ITD2	Provincia Trento	1	0.264	1	0.317	0.518
The Netherlands	NL12	Friesland	1	0.752	1	1	0.520
	NL23	Flevoland	1	0.964	1	1	0.504
	NL33	Zuid-Holland	1	0.838	1	0.901	0.506
	NL41	Noord-Brabant	1	0.779	1	1	0.509
Poland	PL11	Lodzkie	1	0.090	0.069	1	0.360
	PL12	Mazowieckie	1	0.126	0.082	1	0.420
	PL34	Podlaskie	1	0.134	0.068	1	0.401
Sweden	SE01	Stockholm	1	0.303	1	0.613	0.540
	SE07	Mellersta Norland	1	0.512	1	0.485	0.622
	SE08	Övre Norrland	1	0.627	1	0.385	0.685
United Kingdom	UKM2	Eastern Scotland	1	1	1	1	0.800
	UKM3	S-W Scotland	1	0.895	1	0.621	0.812
	UKM4	Highlands & Islands	1	1	1	1	1

388 Source: Our elaboration on European Commission – Agriculture and Rural Development Dataset
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391 **6.   Conclusions**
392 In this paper we used Data Envelopment Analysis (DEA) to address the issue of
393 ranking sustainability of agricultural systems of European regions. Inputs and
394 outputs were defined based on the mosaic approach of sustainability and its three
395 dimensions. We constructed 5 scenarios (i.e. points of view with respect to the
396 importance of the three dimensions of sustainability) by adding various
397 constraints to our basic DEA model. The results indicate that this approach can be
398 considered as highly promising to address the issue of agricultural sustainability.

399 The combination of mosaic approach and DEA allowed us to operationalize the
400 very complex and sophisticated concept of sustainability. In literature we can find
401 alternative approaches, but we think the results of this paper highlight that DEA
402 has several useful and interesting features. The flexibility of DEA and its
403 relatively high accessibility are such that by adding relatively simple constraints
404 significantly different scenarios can be provided without losing too much in terms
405 of complexity and sophistication on the conceptual side. Thus DEA can be used as
406 a tool for sustainability assessment at the level of desk analysis in situations where
407 extracting sustainability assessment directly from the policy-makers would be too
408 complex. A procedure for assessment of sustainability has to take into account
409 how sensitive the results are to changes in the (underlying) assumptions within the
410 adopted methodological approach. We have shown the impact of changing the
411 optimization procedure (for example by introducing balancing constraints) on the
412 efficiency values of the regions. This issue is extremely important in order to
413 provide reliable information to the stakeholders and in order to take correctly into
414 account their needs and preferences. Applying DEA at the EU regional level
415 allowed us to expose the heterogeneity of conditions and performances within
416 each EU Member State and also among them. To our knowledge this is the first
417 paper that explicitly addressed this issue at this level in the EU context. We
418 believe that using regional level data and DEA to take into account this
419 heterogeneity will become increasingly important in following years in order to
420 support European decision making processes related to rural development policy.
421 The results related to variability highlighted the added value of our regional
422 approach in addressing country-comparison analyses. Thus our approach can help
423 to facilitate national-based policy to promote more sustainable regional
424 development. Recent debate about the effectiveness of the EU regional funds
425 allocation reveals that this is an area of research that will require increasing
426 attention in the near future (Crescenzi, 2009). This paper provides clear
427 indications for future research and extensions in this domain, for example in the
428 direction of linking the performances under the different scenarios' assumptions
429 to a set of explanatory variables in order to understand what are the driving factors
430 in the analyzed phenomena. This is an important step in the context of policy-
431 making related to sustainable development of agriculture and rural areas in the EU
432 and a promising area of research for the upcoming years.
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