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## **A fuzzy multi-criteria approach for assessing sustainability of Italian farms**

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### **Summary**

*This work defines a procedure to assess the socio-economic and environmental sustainability of agricultural systems with a particular attention to conventional and organic farming. Firstly, a mathematical programming model calculates the different multi-dimensional outcomes of Italian farms depending on various levels of prices affecting organic products. Those outcomes are the input data for a fuzzy multi-criteria analysis, which processes the various criteria, takes into account different sets of weights for criteria, and, by a ranking of price scenarios, identifies the most desirable and the least desirable level of prices for five groups of regions. The method adopted proves to be sensitive to geographical location and different perspectives. In particular, when the farmers' set of weights is adopted, the highest level of prices represents the most desirable scenario in all groups of regions. On the other side, in all other sets of weights, the lowest level of prices seems to be the most preferable scenario for North-Western regions.*

Keywords: fuzzy multi-criteria analysis, sustainability assessment, organic farming, conventional farming, analytic hierarchy process

JEL Classification codes: C63, C65, D81, Q12, Q51

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# **A fuzzy multi-criteria approach for assessing sustainability of Italian farms**

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## **1. INTRODUCTION**

Sustainability is a complex multi-dimensional concept including economic, social and environmental dimensions. According to the definition provided by the Brundtland Commission, a sustainable development “meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987).

The sustainability concept applies to agriculture, among others. According to Ikerd (1993), sustainable agriculture should be capable of maintaining its productivity and usefulness to society in the long term. This implies that it must be environmentally sound, resource-conserving, economically viable and socially supportive (Sadok et al., 2008). Organic farming claims to have the potential to provide benefits in terms of environmental protection, conservation of non-renewable resources, improved food quality, reduction in output of surplus products and the reorientation of agriculture towards areas of market demand (Lampkin, 1990).

In order “to help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable” (Devuyst et al., 2001), a wide numbers of tools for assessing sustainability have been developed (see Ness et al., 2007, for a review). The key challenges of any sustainability assessment are twofold: (1) the integration of diverse information concerning economic, social and environmental dimensions, and (2) the handling of conflicting aspects of these dimensions as a function of the different views of the stakeholders involved in the assessment process (Sadok et al., 2008).

The assessment of sustainability is therefore increasingly regarded as a typical decision-making problem, leading to the development of sustainability assessment decision-aid methods. Most of these approaches are based on multi-criteria decision methods (Sadok et al., 2008).

The aim of this work is to define a procedure to assess the overall sustainability of agricultural system with a particular attention to conventional and organic approaches. Recently, beside economic sustainability, the social and environmental dimensions are constrained by rules and territory, which a farm cannot elude, and all of them are strongly affected by market conditions in terms of price fluctuations. Price fluctuations are due by a number of causes (e.g. consumer preferences, globalization, and climate change) and considerably affect producer decisions.

In synthesis, this work-in-progress uses data coming from a mathematical programming model (‘MAD’, see Canavari et al., 2013, for details) that calculates the different multi-dimensional outcomes of Italian farms depending on different levels of prices. Those outcomes are the input data for the multi-criteria analysis tool (‘Scryer’, see Mazzocchi et al., 2013, for details), that processes the various indicators (criteria), calculates differences among the various price levels taking into account their different economic,

environmental and social effects , and shows a synthetic index identifying the most favourable level of prices.

Mathematical programming approaches have already shown their advantages compared to econometric approaches as a valid methodology to assess the changes in the agricultural production, and their related environmental, economic and social aspects (Zander and Kächele, 1999; Pacini et al., 2004).

In order to capture the multi-dimensionality of the effects of price variations, a fuzzy multi-criteria tool is applied. Multi-criteria analysis (MCA) approaches are widely used in environmental policy assessments, as they are able to evaluate many dimensions (criteria), assess the importance of each dimension, identify trade-offs, co-benefits and compromise solutions, and include the views of different stakeholders (Greening and Bernow, 2004).

## 2. DESCRIPTION OF DATA AND METHODOLOGY

The information is taken from the Italian farm account database (RICA) using annual and perennial crops (without livestock) farms in the year 2013.

Data used as input for the multi-criteria analysis come from a bio-economic model based on mathematical linear-integer programming (MAD), which identifies the optimal crop plan (conventional or organic), and maximizes the total net income.

The model has been used to assess variation in the market conditions modifying the relative prices of the considered production systems, and to identify the convenience of a farm to shift from one system to another.

Together with net income, the model (in a post-processing stage) also computes a series of indicators based on an environmental model (Canavari et al., 2013). The indicators considered for the MCA are the following:

- Farm carbon emissions per unit surface (ighg, C/ha)
- Agricultural land use intensity (iint , -)
- Ecological focus area index (inat, -)
- Land Biodiversity index (ilbd, -)
- Landscape erodibility index (iler)
- Fertiliser load per unit surface (ipsf, €/ha)
- Pesticide load per unit surface (ipch, €/ha)
- Fuel consumption per unit surface (ipfl, €/ha)
- Average net income per year per unit surface (ivni, €/ha)
- Gross income per year per unit surface (ivmg, €/ha)
- Labour (ilab, €/ha)

The adopted methodology, MCA, allows a comparison of various scenarios based on criteria (indicators) of different dimensions (economic, environmental, social) that can be expressed in both qualitative and quantitative terms. The fuzzy logic, included in Scryer, incorporates the uncertainty

accompanying the estimation of criteria (in case of quantitative estimates, the uncertainty corresponds to the standard error of the estimate).

Furthermore, MCA gives the possibility to assign different weights in order to characterize the relative importance of each criterion. The starting point for the fuzzy multi-criteria calculations through Scryer is a matrix, where the number of rows corresponds to the number of criteria considered, and the columns show the options considered and the weights assigned to each criterion. Each combination of criterion and option shows a couple of values: the estimated value of the criterion/indicator (representing the impact of that option on that criterion) and its uncertainty value.

The fuzzy MCA procedure performed by Scryer can be synthesized as follows (see Appendix 1 for details):

- estimation of distances between options,
- pairwise comparison between options according to each criterion,
- pairwise comparison between options according to all criteria, and
- ranking of options.

At the end of the procedure, we obtain an index (ranging from 0 to 1) as best scenario and another index as worst scenario for each option. We can, therefore, produce a ranking of scenarios: a best scenario ranking (the scenario with the highest best scenario index is the first one), and a worst scenario ranking (the scenario with the highest worst scenario index is the first one).

As MCA gives the possibility to consider different points of view (stakeholders with different opinions and priorities) and to assign different weights in order to characterize the relative importance of each criterion, a sensitivity analysis has been performed in order to show the impacts of changing criteria weights on the model outcomes. Sensitivity analysis procedures can help reduce uncertainty in MCA and the stability of its outputs by illustrating the impact of introducing small changes to specific input parameters on evaluation outcomes. It is perhaps more common to use sensitivity for exploring the changes in the weights given to the criteria rather than checking for changes regarding the criteria values.

For the purpose of present analysis, we have assigned five different sets of weights according to the dimension considered using two different approaches.

The first approach is involving stakeholders, and is based on the Analytic Hierarchy Process (AHP, Saaty 2000, 2013). AHP is related to multi-attribute utility theory, and it uses a hierarchical approach to structure complex information. The first step in applying the method is development of a hierarchy, the three main levels of which are in order from the top down: the overall goal, the main criteria and the indicators describing the socio-economic and environmental aspects considered. After the hierarchical problem structure has been obtained, the next step is evaluation of each element of the problem by pairwise comparisons of all nodes at a given level in relation to the parent node at the previous level. Therefore the different criteria are compared in terms of their satisfaction of the overall goal and the different indicators are compared in terms of their satisfaction of each criterion in turn. This comparison is carried out using the scale from 0 to 9.0. This matrix is used to calculate a priority vector by normalising the principal eigenvector. This priority vector gives the relative importance of the different criteria in achieving the overall goal. The degree of consistency of the data has been checked and since was lower than 10%, the data is

accepted. The AHP method has been applied on two more relevant groups to the purpose of this study, farmers ('wfar') and consumers ('wcon').

The second approach gives equal or different weights to the socio-economic and environmental indicators, as following:

- equal weighting ('wequ') – the criteria are weighted so that both the socio-economic dimension and the environmental dimensions have equal weight;
- socio-economic weighting ('wsec') – socio-economic criteria have a weight of 10, while environmental criteria have a weight of 1;
- environmental weighting ('wenv') – environmental criteria have a weight of 10, while socio-economic criteria have a weight of 1.

The weights assigned according to the 5 different perspectives are shown in Table 1. All weights were normalised, so that each set of weights sums to one.

**Table 1:** Weights assigned to each criterion according to different sets of weights

criteria	wequ	wsec	wenv	wfar	wcon
env_ighg	0.10	0.02	0.18	0.01	0.17
env_iint	0.10	0.02	0.18	0.11	0.05
env_inat	0.10	0.02	0.18	0.06	0.08
env_ilbd	0.10	0.02	0.18	0.04	0.07
env_iler	0.10	0.02	0.18	0.13	0.13
sec_ipsf	0.08	0.15	0.02	0.05	0.04
sec_ipch	0.08	0.15	0.02	0.05	0.05
sec_ipfl	0.08	0.15	0.02	0.05	0.05
sec_ivni	0.08	0.15	0.02	0.25	0.09
sec_ivmg	0.08	0.15	0.02	0.16	0.06
sec_ilab	0.08	0.15	0.02	0.10	0.22

Source: own elaboration

Instead of performing the analysis at a national level, results are provided by grouping farms into the five Italian groups of regions, corresponding to the first level of the Nomenclature of territorial units for statistics (NUTS) established for the territory of the European Union (EU):

- North-West (Aosta Valley, Liguria, Lombardy, Piedmont)
- North-East (Emilia-Romagna, Friuli-Venezia Giulia, Trentino-Alto Adige/Südtirol, Veneto)
- Centre (Lazio, Marche, Tuscany, Umbria)
- South (Abruzzo, Apulia, Basilicata, Calabria, Campania, Molise)
- Isles (Sardinia, Sicily)

MCA has been finally used to explore price scenario applying variations on prices of organic products.

Different results correspond to MAD ability to adapt crop choices (rotation, see Canavari et al., 2013) and orientation (stay on conventional or shift to organic). Five price scenarios have been tested: -50% (0.5), -20% (0.8), no change (baseline scenario, i.e. 1.0), +20% (1.2), +100% (2.0).

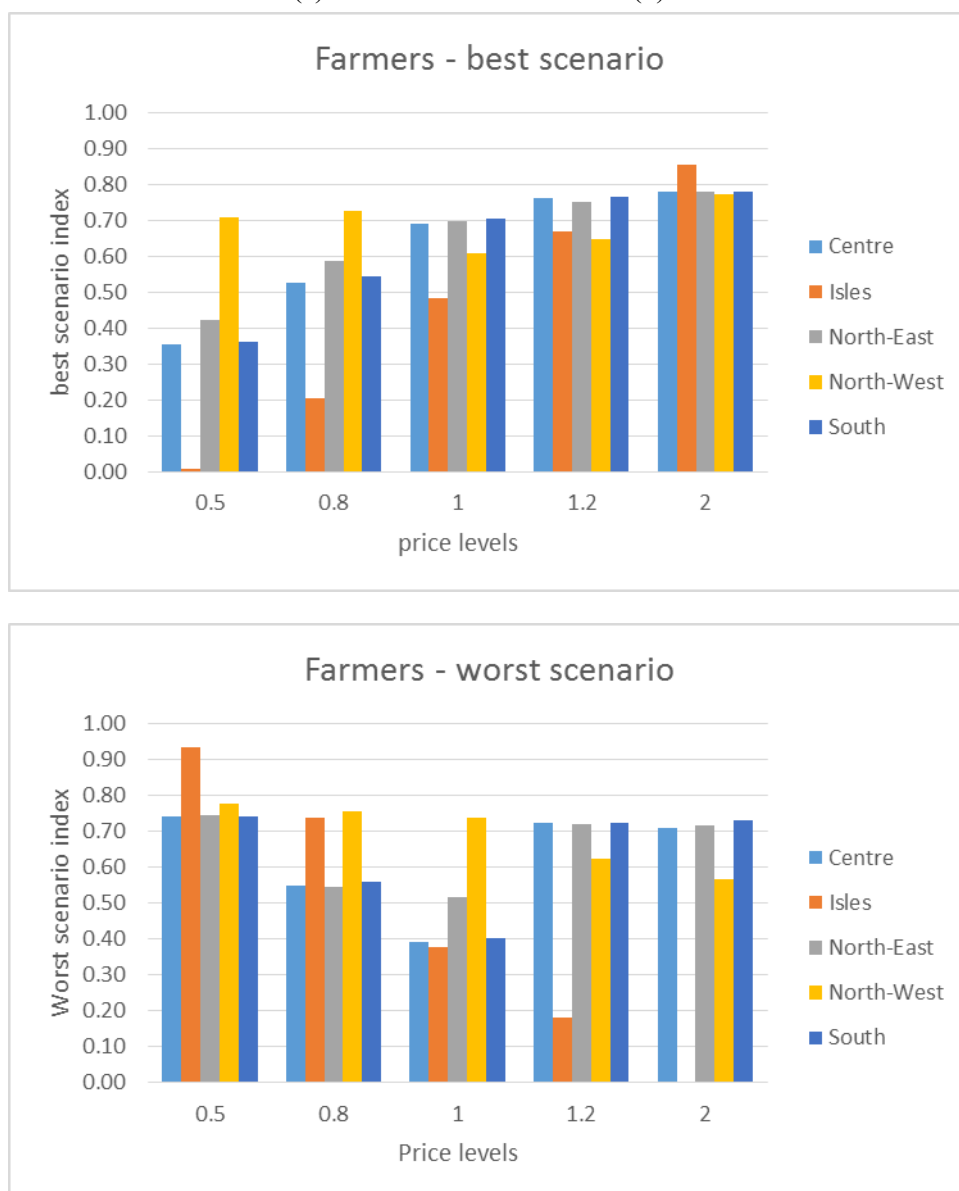
### 3. DISCUSSION OF RESULTS

The matrices of impacts (one for each group of regions) which represent the input data for the Stryer procedure, can be found in Appendix 2, where the average of the estimates derived from the MAD model and the standard error of the mean (as a measure of uncertainty) is included for each criterion for each scenario.

Results from the MCA are shown in Table 1, for each territorial area and each set of weights. An ‘unweighted’ set of results are also given, as a benchmark for all other set of weights.

If the farmers’ point of view is adopted (see Figure 1), the most preferable price scenario would be a doubling of prices (scenario 5), for all groups of regions. Very neatly, the worst price scenario would be a strong decrease of prices. However, it should be noted that the fifth scenario is the second worst scenario for North-Eastern and Southern Italian farms, according to MCA results. So, doubled prices is not only the most favourable scenario, but could also turn out to be an unfavourable scenario for those two groups of regions, indicating that there are opportunities but also risks with increasing prices of organic products.

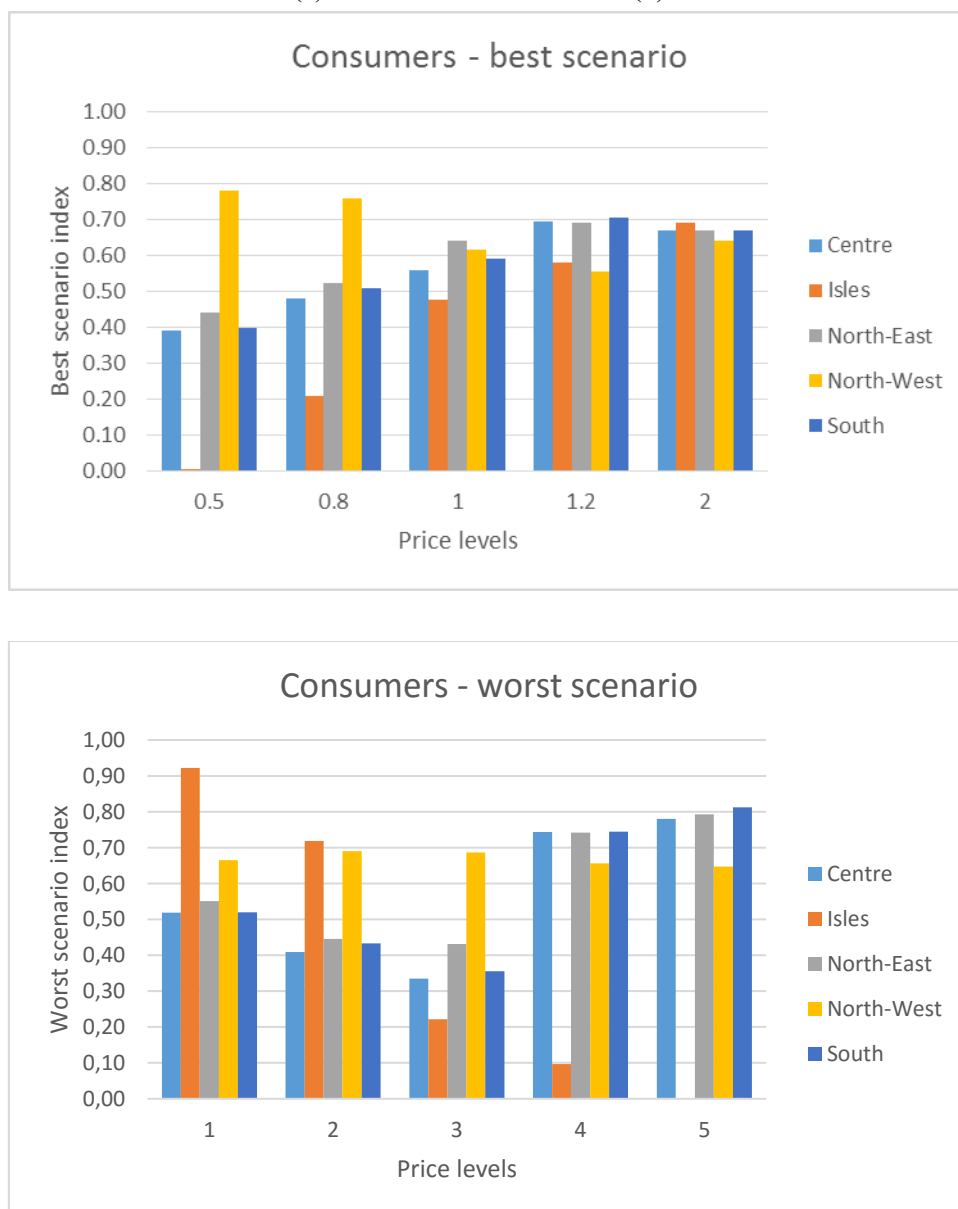
**Figure 1:** Best scenario index (a) and worst scenario index (b) results with farmers’ set of weights



Source: own elaboration

If we consider the consumers' set of weights (see Figure 2), on one side, a slight (for 3 groups of regions) and a high (for one group) increase of prices would be desirable. On the other side, for North-Western Italy the desirable scenario would be half the baseline prices. However, if we look at the results for the worst scenario, a double increase of prices appears to be the worst scenario for 3 regions, while for North-West and the Isles a decrease in prices would turn out to be the worst scenario. There are 2 interesting cases to be noted. The first one is the Isles, where results from both the best and worst scenario indexes reveal a clear desirability for increasing prices. The second one is North-West, where results are not obvious, as both the best and worst scenario indexes are higher for low levels of prices, and there is not a huge difference among the values obtained for all five scenarios. This could probably be due to a higher uncertainty in the quantitative estimates of the criteria for the North-West, compared to the other groups of regions, especially the Isles.

**Figure 2:** Best scenario index (a) and worst scenario index (b) results with consumers' set of weights

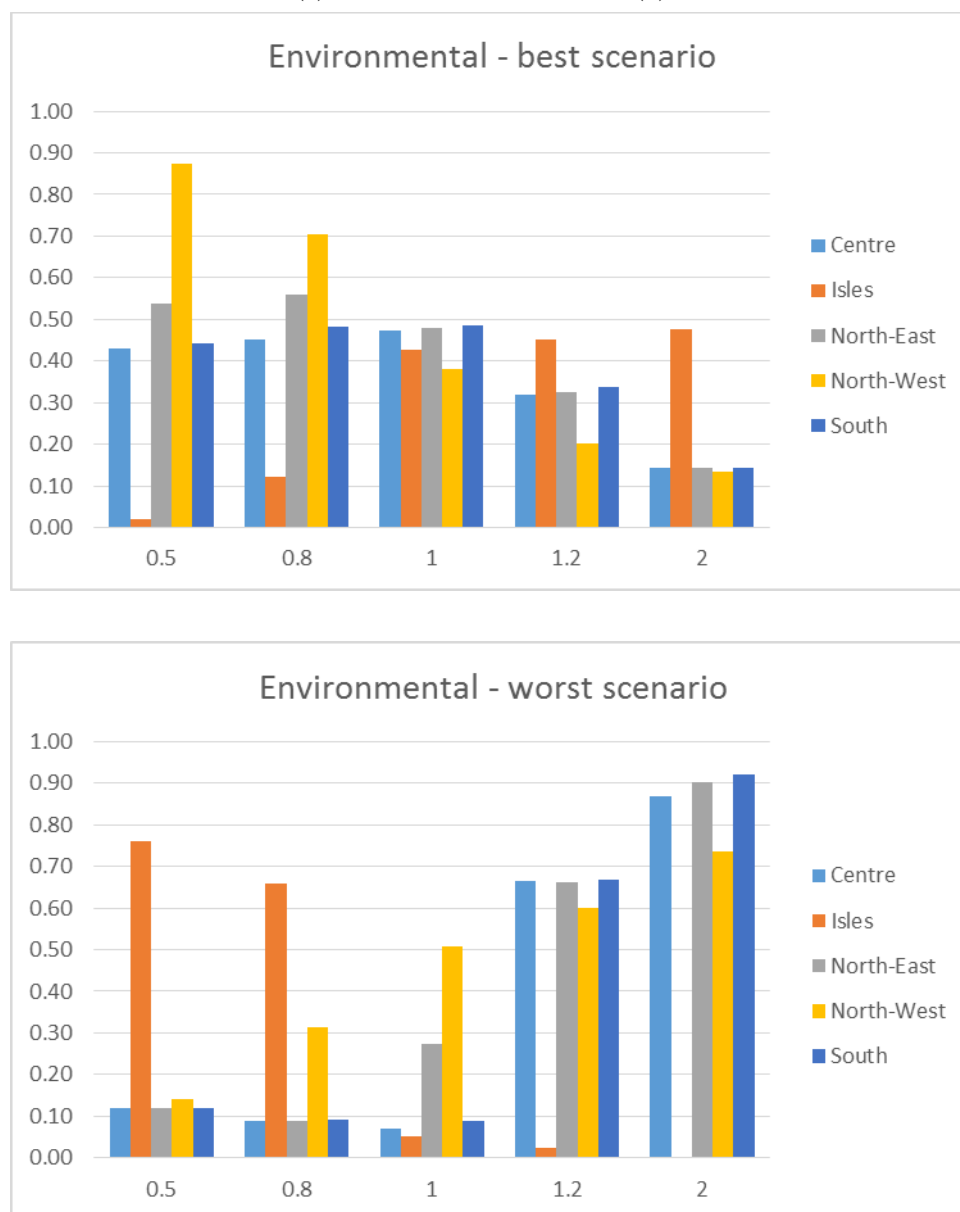


Source: own elaboration



If the environmental perspective is adopted, results are quite heterogeneous among the groups of regions (see Figure 3). For two groups (Centre and South), the most desirable solution would be the status quo. For other two groups (North-East and North-West), a decrease in prices would be most desirable for the environment. On the opposite side, for the Isles the best scenario would be an increase of prices. The difference between the Isles and the other groups is even more evident for the worst scenario, where the half prices scenario has the highest value for the Isles, and the doubled level of prices has the highest value for the other groups of regions. It can also be noted that there is clear pattern, although in opposite directions, for both the Isles and North-West, while for the other groups the values for the five scenarios do not greatly differ and are not always progressive.

**Figure 3:** Best scenario index (a) and worst scenario index (b) results with the environmental set of weights

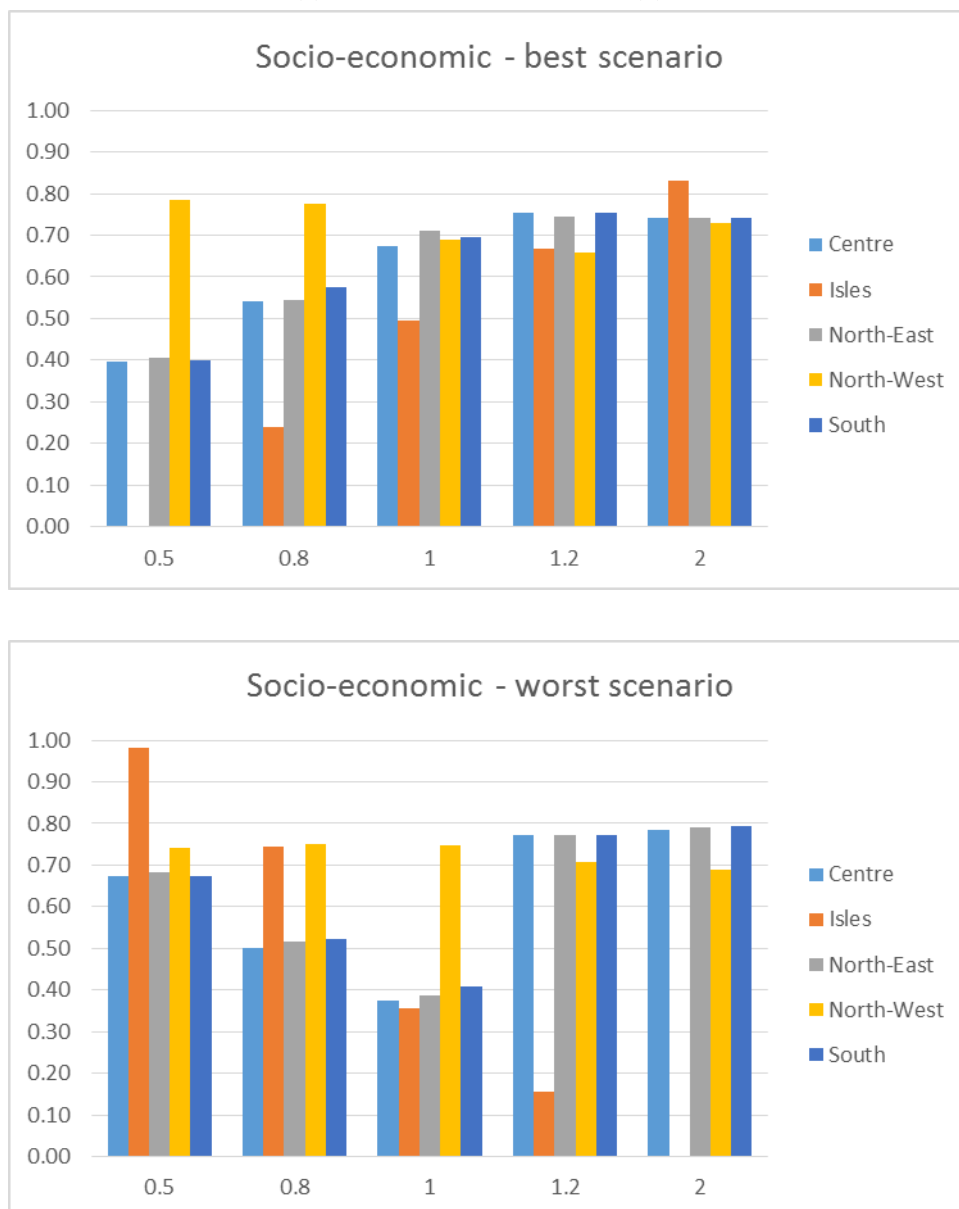


Source: own elaboration

When the socio-economic perspective is primarily accounted for (see Figure 4), the North-West show opposite results (with a desirability for the half prices) from the other groups of regions (showing a preference for increasing levels of prices with respect to the baseline situation). If we look at the worst

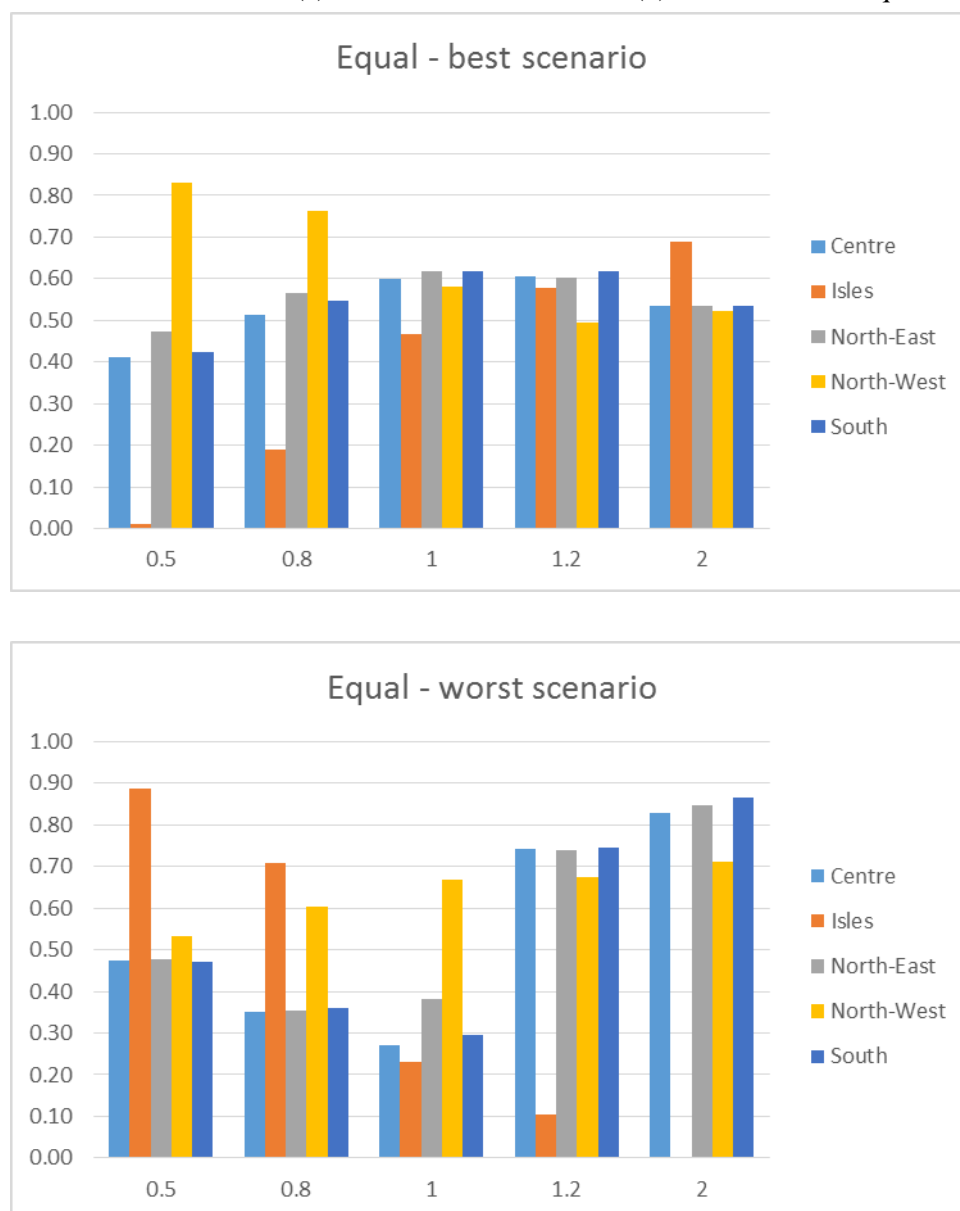
scenario index, we can observe that for 3 groups of regions (Centre, North-East, South), high levels of prices can turn out to be the least desirable scenario, while for Isles and North-West, low levels of prices show the highest index values. It can also be noted that there is clear pattern for the Isles towards a strong preference for high price levels, while for the other groups the values for the five scenarios do not greatly differ and are not always progressive. This means that, for the latter groups, an increase of prices could turn out to be the most, but also the least, desirable situation. This is probably due to a high uncertainty in the estimates of the criteria.

**Figure 4:** Best scenario index (a) and worst scenario index (b) results with the socio-economic set of weights



Source: own elaboration

If we assign an equal weight to the socio-economic and the environmental indicators, results in terms of ranking correspond to the environmental set of weights (see Figure 5). For 3 groups of regions, higher prices compared to the baseline scenario are the most desirable scenario. For the North-East, the best scenario is the status quo, and for the North-West, the best scenario is the lowest level of prices.

**Figure 5:** Best scenario index (a) and worst scenario index (b) results with the equal set of weights

Source: own elaboration

**Table 1.** Results from the MCA

Weighting	Indexes	Scenarios - Price levels	Centre	Isles	North-East	North-West	South
NOT WEIGHTED	Best scenario	1 0.5	0.41	0.01	0.47	<b>0.83</b>	0.42
		2 0.8	0.52	0.20	0.56	0.76	0.55
		3 1	0.61	0.47	<b>0.63</b>	0.60	0.63
		4 1.2	<b>0.63</b>	<b>0.59</b>	0.62	0.52	<b>0.64</b>
		5 2	0.57	0.71	0.57	0.55	0.57
	Worst scenario	1 0.5	0.50	<b>0.90</b>	0.50	0.56	0.50
		2 0.8	0.37	0.71	0.38	0.62	0.38
		3 1	0.28	0.25	0.38	0.68	0.31
		4 1.2	0.75	0.11	0.75	0.68	0.75
		5 2	<b>0.82</b>	0.00	<b>0.84</b>	<b>0.71</b>	<b>0.86</b>

EQUAL	Best scenario	1	0.5	0.41	0.01	0.47	<b>0.83</b>	0.42
		2	0.8	0.51	0.19	0.57	0.76	0.55
		3	1	0.60	0.47	<b>0.62</b>	0.58	0.62
		4	1.2	<b>0.61</b>	0.58	0.60	0.49	<b>0.62</b>
		5	2	0.54	<b>0.69</b>	0.54	0.52	0.54
	Worst scenario	1	0.5	0.47	<b>0.89</b>	0.48	0.53	0.47
		2	0.8	0.35	0.71	0.35	0.60	0.36
		3	1	0.27	0.23	0.38	0.67	0.30
		4	1.2	0.74	0.10	0.74	0.68	0.74
		5	2	<b>0.83</b>	0.00	<b>0.85</b>	<b>0.71</b>	<b>0.87</b>
ENVIRONMENTAL	Best scenario	1	0.5	0.43	0.02	0.54	<b>0.88</b>	0.44
		2	0.8	0.45	0.12	<b>0.56</b>	0.70	0.48
		3	1	<b>0.47</b>	0.43	0.48	0.38	<b>0.49</b>
		4	1.2	0.32	0.45	0.33	0.20	0.34
		5	2	0.14	<b>0.48</b>	0.14	0.13	0.14
	Worst scenario	1	0.5	0.12	<b>0.76</b>	0.12	0.14	0.12
		2	0.8	0.09	0.66	0.09	0.31	0.09
		3	1	0.07	0.05	0.27	0.51	0.09
		4	1.2	0.67	0.02	0.66	0.60	0.67
		5	2	<b>0.87</b>	0.00	<b>0.90</b>	<b>0.74</b>	<b>0.92</b>
SOCIO-ECONOMIC	Best scenario	1	0.5	0.40	0.00	0.40	<b>0.78</b>	0.40
		2	0.8	0.54	0.24	0.54	0.77	0.58
		3	1	0.68	0.49	0.71	0.69	0.70
		4	1.2	<b>0.75</b>	0.67	<b>0.75</b>	0.66	<b>0.76</b>
		5	2	0.74	<b>0.83</b>	0.74	0.73	0.74
	Worst scenario	1	0.5	0.67	<b>0.98</b>	0.68	0.74	0.67
		2	0.8	0.50	0.74	0.52	<b>0.75</b>	0.52
		3	1	0.38	0.36	0.39	0.75	0.41
		4	1.2	0.77	0.16	0.77	0.71	0.77
		5	2	<b>0.79</b>	0.00	<b>0.79</b>	0.69	<b>0.79</b>
FARMERS	Best scenario	1	0.5	0.35	0.01	0.42	0.71	0.36
		2	0.8	0.53	0.20	0.59	0.73	0.54
		3	1	0.69	0.49	0.70	0.61	0.71
		4	1.2	0.76	0.67	0.75	0.65	0.77
		5	2	<b>0.78</b>	<b>0.86</b>	<b>0.78</b>	<b>0.77</b>	<b>0.78</b>
	Worst scenario	1	0.5	<b>0.74</b>	<b>0.93</b>	<b>0.74</b>	<b>0.78</b>	<b>0.74</b>
		2	0.8	0.55	0.74	0.54	0.76	0.56
		3	1	0.39	0.38	0.52	0.74	0.40
		4	1.2	0.72	0.18	0.72	0.63	0.72
		5	2	0.71	0.00	0.72	0.57	0.73
CONSUMERS	Best scenario	1	0.5	0.39	0.00	0.44	<b>0.78</b>	0.40
		2	0.8	0.48	0.21	0.52	0.76	0.51
		3	1	0.56	0.48	0.64	0.62	0.59
		4	1.2	<b>0.69</b>	0.58	<b>0.69</b>	0.55	<b>0.70</b>
		5	2	0.67	<b>0.69</b>	0.67	0.64	0.67
	Worst scenario	1	0.5	0.52	<b>0.92</b>	0.55	0.67	0.52
		2	0.8	0.41	0.72	0.45	<b>0.69</b>	0.43
		3	1	0.33	0.22	0.43	0.69	0.36
		4	1.2	0.74	0.10	0.74	0.66	0.74
		5	2	<b>0.78</b>	0.00	<b>0.79</b>	0.65	<b>0.81</b>

Source: own elaboration

#### 4. FINAL CONSIDERATIONS

The fuzzy multi-criteria procedure employed proves to be sensitive to geographical location and different perspectives. In particular, when the farmers' set of weights is adopted, the highest level of prices represents the most desirable scenario in all groups of regions. On the other side, in all other sets of weights, the lowest level of prices seems to be the most preferable scenario for North-Western regions. Results from the MCA show that the degree of 'desirability' of a price level is not always 'linear', i.e. a progressive increase / decrease in prices does not necessarily mean that is progressively more desirable. We can also observe that there is no difference among location of groups of regions, i.e. North, South & Isles, Centre.

On a methodological point of view, this work can generate discussion on the choice of MCA as the appropriate method of analysis for assessing different levels of prices of organic products. Furthermore, the opportunity to consider additional or alternative criteria for the assessment can be discussed.

As far as policy analysis is concerned, points for discussion could be the appropriateness of the identified levels of prices, and the possibility to consider different options.

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## APPENDIX 1 – SCRYER PROCEDURE

The fuzzy multi-criteria tool, Scryer, involves a series of steps. Scryer was originally developed for the ex ante assessment of qualitative and quantitative food safety regulatory proposals. As for this work all criteria are expressed in quantitative terms, description of the procedure is limited to quantitative estimates. See Mazzocchi et al. (2013) for all details.

The input data is a matrix including the mean of the estimates and the standard error of the mean for each criteria and each scenario.

### *Calculation of distances between options*

First, pairwise distances between scenarios need to be computed for each criterion. As criteria are all expressed in quantitative (stochastic) terms, we assume a normal probability distribution and adopt the Hellinger distance between normally distributed variables:

$$DH = \sqrt{1 - \sqrt{\frac{2s_1s_2}{s_1^2 + s_2^2}} e^{-\frac{1}{4} \frac{(x_{i1} - x_{i2})^2}{s_1^2 + s_2^2}}} \quad (A.1)$$

where  $s_1$  and  $s_2$  are the standard errors of the estimated impacts  $x_{i1}$  and  $x_{i2}$ , respectively.

After rescaling the equation, distances are bound between 0 (minimum distance) and 1 (maximum distance), which makes them comparable. This ultimately allows for simultaneous consideration of multiple measurement units.

### *Credibility values for pairwise policy comparison*

These pairwise distances are the basis to assign credibility values to a set of 6 sentences (preference relations) on the comparison between two scenarios according to a given criterion, i.e. that one scenario is much better (better, approximately equal, equal, worse, much worse) than the alternative, for a given criterion. This generates 6 credibility values for each of the 11 criteria and each pair of scenarios. Credibility values are bound between 0 (not credible at all) and 1 (maximum credibility) and are a function of the computed distance. For example, the credibility index that ‘scenario A is much better than scenario B’ in terms of greenhouse gas emissions becomes larger as the distance between A and B increases, provided that the positive impact of A is larger than the one of B. Vice versa, in this case, the credibility that ‘scenario A is much worse than scenario B’ will become smaller. This ‘credibility’ framework is consistent with the fuzzy logic and the presence of uncertainty on the expected outcomes of a price scenario.

The six ‘preference relations’ between two scenarios ( $P_1$  and  $P_2$ ) for each of the  $c$  criteria are as follows:

- >>  $P_1$  is much better than  $P_2$  (according to criterion  $i$ )
- >  $P_1$  is better than  $P_2$
- $\cong$   $P_1$  is more or less like  $P_2$
- =  $P_1$  is identical to  $P_2$
- <  $P_1$  is worse than  $P_2$
- <<  $P_1$  is much worse than  $P_2$

For each of these statements, the *credibility value* is generated, based on the semantic distances ( $D$ ) between the two estimates for the same criterion (e.g.  $x_{i1}$  and  $x_{i2}$  as defined above), and some fixed thresholds ( $\chi$ ), as follows:

$$c_{>>,i}(P_1, P_2) = \begin{cases} 0 & \text{if } x_{i1} \leq x_{i2} \\ \frac{1}{\left(1 + \frac{\chi_{>>}^2 (\sqrt{2} - 1)}{D^2}\right)} & \text{if } x_{i1} > x_{i2} \end{cases}$$

(much better)

$$c_{>,i}(P_1, P_2) = \begin{cases} 0 & \text{if } x_{i1} \leq x_{i2} \\ \frac{1}{\left(1 + \frac{\chi_{>}^2}{D^2}\right)} & \text{if } x_{i1} > x_{i2} \end{cases}$$

(better)

$$c_{\approx,i}(P_1, P_2) = e^{-\left(\frac{\ln 2}{\chi_{\approx}} D\right)}$$

(approximately equal)

$$c_{=,i}(P_1, P_2) = e^{-\left(\frac{\ln 2}{\chi_{=}} D^2\right)}$$

(equal)

$$c_{<,i}(P_1, P_2) = \begin{cases} 0 & \text{if } x_{i1} \geq x_{i2} \\ \frac{1}{\left(1 + \frac{\chi_{<}^2}{D^2}\right)} & \text{if } x_{i1} < x_{i2} \end{cases}$$

(worse)

$$c_{<<,i}(P_1, P_2) = \begin{cases} 0 & \text{if } x_{i1} \geq x_{i2} \\ \frac{1}{\left(1 + \frac{\chi_{<<}^2 (\sqrt{2} - 1)}{D^2}\right)} & \text{if } x_{i1} < x_{i2} \end{cases}$$

(much worse)



*Aggregation across criteria and weights (pairwise comparison of scenarios)*

The next step is the aggregation of the pairwise comparison between two scenarios across the criteria. Aggregation is pursued through a relatively straightforward average – called preference intensity index – of the credibility values for each pairwise comparison of scenarios, which enables the introduction of relative weights to discriminate across criteria with different relevance. This is a key element of flexibility, which may reflect different stakeholder perspectives (e.g. the relative weight of environmental outcomes versus economic costs for the farmers) and allows to check for robustness of the scenario ranking in relation to different preference structures, by reproducing the analysis with different sets of weights.

The equation for the aggregate preference intensity index for each of the 6 preference statements (hereafter generally indicated with a subscript \*) can be written as:

$$\mu_*(P_1, P_2) = \frac{\sum_{i=1}^c \max(c_{*,i} - \alpha, 0) w_i}{\sum_{i=1}^c |c_{*,i} - \alpha| w_i} \quad (\text{A.2})$$

where  $w_i \in [0, 1]$  (with  $i: 1, \dots, c$ ) are the weights assigned to each criterion,  $\sum_{i=1}^c w_i = 1$ . These weights are computed in Scryer as a function of statements on the relative importance of each criterion.

*Ranking of policies*

The final step of Scryer consists in the final ranking of scenarios. A measure of how the scenario ranks compared to all alternative scenarios is based on an average of the preference intensity indices. At this stage, the six preference statements on pairwise scenario comparison are simplified into two key categories: the statement that a given scenario is ‘the best scenario and the counter-statement that the same scenario is ‘the worst’. According to the fuzzy logic, a membership value to each of the two statements needs to be calculated for each scenario. The ‘best’ scenario membership value is a ranking index which is termed as  $\phi^+$ , while the degree of belonging to the ‘worst’ scenario is quantified by the ranking index  $\phi^-$ .

These synthetic indices are based on the ‘performance’ of each scenario against all others, where the times the option is ‘much better’ or ‘better’ than the alternatives increase  $\phi^+$ , and the occurrences of the ‘worse’ or ‘much worse’ preference intensity indices generate an increase of  $\phi^-$ .

$$\phi^+(P_i) = \frac{\sum_{j \neq i}^p \mu_{\gg}(P_i, P_j) + \mu_{>}(P_i, P_j)}{2(p-1)} \quad (\text{A.3})$$

$$\phi^-(P_i) = \frac{\sum_{j \neq i}^p \mu_{<}(P_i, P_j) + \mu_{\ll}(P_i, P_j)}{2(p-1)} \quad (\text{A.4})$$

where  $p$  is the number of scenarios being considered. The same indicators can be computed without the entropy weighting, by omitting the terms in square brackets and using  $2(p-1)$  as the denominator.

For each scenario, the above equations aggregate the much better (much worse) and better (worse) preference intensity index, to generate an aggregate preference index for the best (worst) scenario. They can be interpreted as a degree of membership to the statements that ‘Scenario alternative  $i$  is the best scenario’ and ‘Scenario  $j$  is the worst scenario’. All scenario alternatives can now be ranked according to  $\varphi^+$  and  $\varphi^-$ , which range between 0 and 1.

**APPENDIX 2 - MATRICES OF GROUPS OF REGIONS**

criteria	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
North-West										
env_iler	-2.635	0.011	-2.666	0.010	-3.494	0.020	-3.502	0.020	-3.509	0.020
sec_ipsf	-38.697	0.824	-46.373	1.669	-671.466	4.984	-675.809	4.765	-679.480	4.622
env_ighg	-361.639	8.398	-406.827	11.873	-3733.704	21.295	-3755.675	20.357	-3770.558	19.869
env_ilbd	4.404	0.287	4.410	0.287	4.274	0.288	4.273	0.288	4.272	0.288
env_iint	-1.425	0.007	-1.461	0.008	-2.211	0.009	-2.217	0.009	-2.223	0.008
sec_ipch	-34.439	1.685	-38.889	2.160	-846.769	6.006	-851.416	5.735	-855.796	5.540
sec_ipfl	-259.006	5.934	-290.815	8.376	-2632.889	14.975	-2648.362	14.311	-2658.828	13.968
env_inat	0.028	0.003	0.028	0.003	0.028	0.003	0.028	0.003	0.028	0.003
sec_ivmg	2029.160	97.631	2492.276	140.030	31579.450	135.185	37785.228	169.307	62447.841	314.542
sec_ivni	1252.323	72.655	1439.976	92.208	4371.335	94.406	10532.126	83.488	35272.323	161.416
sec_ilab	301.565	10.221	443.222	28.854	21018.103	188.092	21164.898	178.560	21361.553	167.064
North-East										
env_iler	-2.692	0.010	-2.692	0.010	-2.700	0.010	-2.755	0.008	-3.413	0.020
sec_ipsf	-65.234	2.097	-65.215	2.093	-65.724	2.090	-127.213	7.635	-876.255	11.814
env_ighg	-543.691	23.230	-542.946	23.115	-545.083	22.746	-1098.399	69.386	-6410.331	76.719
env_ilbd	2.353	0.099	2.353	0.099	2.354	0.099	2.355	0.099	2.298	0.100
env_iint	-1.558	0.010	-1.558	0.010	-1.567	0.010	-1.624	0.011	-2.202	0.007
sec_ipch	-68.226	3.620	-68.384	3.646	-67.711	3.627	-123.402	7.797	-768.733	7.935
sec_ipfl	-386.819	16.337	-386.295	16.256	-387.609	15.989	-777.292	48.832	-4516.515	54.010
env_inat	0.005	0.001	0.005	0.001	0.005	0.001	0.005	0.001	0.005	0.001
sec_ivmg	4687.336	223.339	5107.899	245.941	5421.504	262.385	8538.634	436.675	49653.394	346.821
sec_ivni	3537.686	196.501	4050.994	231.252	4303.224	247.289	4634.747	262.859	21892.484	126.390
sec_ilab	567.599	35.019	567.599	35.019	599.685	37.893	1876.098	153.004	19624.987	243.422
Centre										
env_iler	-2.711	0.006	-2.711	0.006	-2.711	0.006	-3.132	0.014	-3.509	0.012
sec_ipsf	-58.505	1.004	-58.486	1.004	-58.760	1.004	-325.553	8.955	-514.514	5.969
env_ighg	-559.411	12.026	-557.162	11.971	-557.266	11.957	-2617.750	69.298	-3943.937	47.749
env_ilbd	4.224	0.175	4.224	0.175	4.225	0.175	4.200	0.175	4.160	0.175
env_iint	-1.565	0.007	-1.565	0.007	-1.566	0.007	-1.940	0.010	-2.254	0.004
sec_ipch	-64.504	1.800	-64.840	1.816	-65.345	1.825	-455.270	11.479	-874.699	3.709
sec_ipfl	-397.897	8.450	-396.318	8.411	-396.393	8.401	-1846.313	48.769	-2781.305	33.614
env_inat	0.025	0.002	0.025	0.002	0.025	0.002	0.025	0.002	0.025	0.002
sec_ivmg	3478.006	106.601	3774.072	120.939	3960.132	129.626	19142.798	418.916	51005.328	217.145
sec_ivni	2337.605	84.384	2664.071	100.477	2854.781	109.680	3513.077	114.670	22162.267	127.829
sec_ilab	516.737	12.793	514.386	12.725	512.835	12.689	10424.056	310.801	22681.945	133.758
South										
env_iler	-2.847	0.009	-2.847	0.009	-2.850	0.009	-2.920	0.010	-3.494	0.012
sec_ipsf	-82.953	1.957	-82.757	1.956	-83.930	2.034	-164.321	7.147	-416.364	5.040
env_ighg	-778.969	18.301	-774.392	18.246	-784.131	18.836	-1381.541	50.285	-3291.094	36.447
env_ilbd	2.323	0.036	2.323	0.036	2.325	0.036	2.317	0.036	2.119	0.039
env_iint	-1.755	0.008	-1.755	0.008	-1.757	0.008	-1.815	0.008	-2.279	0.003
sec_ipch	-80.316	2.216	-80.169	2.218	-80.989	2.273	-153.042	6.056	-948.841	6.600
sec_ipfl	-552.266	12.878	-549.044	12.838	-555.901	13.254	-976.396	35.399	-2320.793	25.661
env_inat	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
sec_ivmg	4262.732	143.502	4622.852	162.336	4907.130	175.364	8901.793	331.266	45142.238	226.252
sec_ivni	2684.227	109.367	3052.129	128.168	3276.766	139.073	3940.434	148.339	15184.125	212.492
sec_ilab	700.836	18.832	693.761	18.701	704.300	19.443	1642.543	86.366	23268.086	211.883
Isles										
env_iler	-3.603	0.030	-3.610	0.029	-3.541	0.028	-3.541	0.028	-3.540	0.028
sec_ipsf	-1578.847	20.244	-1565.993	21.308	-864.923	8.063	-861.342	8.145	-862.315	8.130
env_ighg	-8109.983	57.331	-7982.443	69.747	-4433.660	48.729	-4430.525	48.763	-4446.306	49.000
env_ilbd	5.078	0.421	5.068	0.421	5.068	0.421	5.068	0.421	5.068	0.421
env_iint	-2.409	0.012	-2.415	0.011	-2.356	0.009	-2.356	0.009	-2.355	0.009
sec_ipch	-1635.198	18.611	-1619.690	20.198	-1358.365	16.785	-1355.108	17.044	-1353.261	17.189
sec_ipfl	-5713.364	40.360	-5623.641	49.092	-3125.371	34.305	-3123.170	34.329	-3134.282	34.502
env_inat	0.031	0.004	0.031	0.004	0.031	0.004	0.031	0.004	0.031	0.004

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sec_ivmg	44174.349	458.955	44681.784	437.417	58804.510	615.970	70169.502	738.658	114768.495	1254.321
sec_ivni	16144.103	232.588	16531.576	228.812	20024.569	223.967	31334.159	322.281	76563.482	832.439
sec_ilab	15484.721	171.010	15833.339	150.824	29375.184	468.385	29508.523	455.690	29613.823	445.769

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Source: Own elaboration

Notes: s.e. stands for standard error of the mean