Assessment of aggregated indicators of sustainability using PCA: the case of apple trade in Spain

J. Soler-Rovira[1] and P. Soler-Rovira[2]
[1]Departamento de Produccion Vegetal: Fitotecnia, Escuela Universitaria de Ingenieria Tecnica Agricola, Universidad Politecnica de Madrid, Ciudad Universitaria s/n, 28040-Madrid, Spain, jose.soler@upm.es
[2]Instituto de Ciencias Agrarias, Centro de Ciencias Medioambientales, C.S.I.C., Serrano 115 dpdo., 28006-Madrid, Spain.

Keywords:, ecological footprint, economic impact, environmental indicators, life cycle assessment, multivariate analysis, social impact, sustainability.

Abstract
Environmental, economic and social impacts of intensive agricultural production, but also those regarding to international trade of fresh apples in Spain, were studied by the multivariate statistical method of principal components analysis (PCA). Environmental indicators were developed for 36 countries using life cycle analysis of apple cultivation and transport, weighting the results on a global or local scale. Economic and social indicators were also calculated considering macro and microeconomic aspects and also farm or society characteristics. PCA was applied to each set of indicators and aggregated indices were computed for each dimension of sustainability with the results of the analysis. The selected indicators explained with good agreement the differences in sustainability between countries and the synthetic indices ranked them all. Some of them showed a high relative sustainability, while other presented low values, due to low environmental, economic or social sustainability values of the aggregated indices.

Introduction
In recent years, international trade of fresh fruits and vegetables has also increased due to market liberalisation and technical development of agricultural practices, conservation processes and transport facilities. There are a variety of complex environmental, economic and social impacts regarding international trade. Those impacts arise at either global or local scales, pertaining to issues as energy consumption, emission of pollutants, degradation of natural resources, land-use changes, etc. By the other hand, economic growth takes place in exporting countries, but wealth often shows and unequal distribution between the populations (Wurtenberger *et al.*, 2006). Consequently, there is a need to assess the environmental, economic and social impacts of intensive agricultural production but also those regarding to international trade.

Spain is a big fruit producer with approximately 13 million tonnes in 1,300,000 ha of cultivated land, which represents almost 30% of the harvested area of fruits in the EU (FAO, 2008). The trade flows of agricultural products with other countries show a balanced state since the imports equals the exports. The main exported agricultural product is the fresh fruit (4,300 million euro in 2005), but Spain also imports fruits for 1,300 million euro (MAPA, 2006). Apple production and trade is a good case study because it accounts for 14% of total fruit consumption in Spain, and 29% of this quantity is imported from other countries (MAPA, 2006). Spanish imports of apple have been increased in the last years and the main origins are France, Italy, Germany and Portugal in the EU, and Chile and Argentina in South America (FAO, 2008). Imports from France have decreased in the period 2000-05, but the other origins show an increasing trend, except Portugal that shows a flat evolution.

The sustainability of this apple trade may be assessed by a number of indicators that reveal the impacts of their cultivation and transport from producer countries to the Spanish market. These indicators should be useful for policy-makers at the roundtables where trends are monitored and sustainable trade policies are introduced and evaluated. Even more, they can be helpful product information for consumers and their associations towards a consumption trend that accomplish a set of sustainabilitysensitive criteria (Levitan, 2000). Indicators should be synthesized into an appropriate indicator that contains a lot of information but, at the same time, it is easy to understand by the end-users (policy-makers, consumers, etc.). Aggregated indicators help to communicate the information succinctly and make easier to distinguish patterns in the data by formalizing the aggregation process that is often done implicitly, subjectively and intuitively (Jollands *et al.*, 2004). Nevertheless, it is necessary to consider the potential limitations of the synthetic indicators since they may mask and simplify the complexity of environmental, social and economic systems.

In the development of aggregated indicators problems arise when the indices that build up the indicator and the weights of each index have to be selected. Therefore, principal components analysis (PCA) can be used as an objective approach to choose the indices that show higher variability within the studied observations and to set the weights as a function of the explained variance (Jollands *et al.*, 2004). However, PCA is limited to ex-post analysis and it is not an appropriate tool for prospective investigations. Additionally, this analysis allows making an internal sustainability evaluation between countries, giving a relative value of sustainability.

PCA have been used in several studies that include large sets of data, i.e. ecology and water quality, landscape characterization, pesticide screening or food quality. PCA has been applied to select proper and representative variables that could explain the variability included in the original data. The usefulness of PCA have been demonstrated to select environmental (Yu *et al.*, 1998), energy intensity (Bernard and Cote, 2005), eco-efficiency (Jollands *et al.*, 2004) and agri-environmental indicators (Soler-Rovira and Arroyo-Sanz, 2003; Soler-Rovira and Arroyo-Sanz, 2004). For example, the latter authors selected nutrient management indicators and classified the Spanish provinces and districts applying cluster analysis to the results from the PCA. Finally, synthetic indicators have been aggregated by PCA for data obtained in studies on sustainable agricultural systems (Sands and Podmore, 2000), irrigation schemes (Rodriguez-Diaz *et al.*, 2008), poverty and human development (Antony and Visweswara Rao, 2007) and sustainable development and environmental quality (Castro, 2002; Jha and Murthy, 2003; Escobar, 2006). However, the methodology used to build up the aggregated indicator differs between authors and none of them have applied the aggregation with PCA combined with life cycle analysis on sustainability of production and trade.

The aim of this work is to assess the sustainability of apple production and trade flows in Spain by the development of aggregated indexes obtained by multivariate analysis (PCA) of individual indicators (economic, social and environmental).

Method

The methodology used is PCA, so first of all this multivariate statistical tool is briefly described in this section. Secondly, the characteristics of apple trade in Spain are evaluated and the main apple producing countries are selected. The next steps are to choose a set of indicators that can be used to characterize the sustainability of the environmental, economic and social dimensions of apple trade. Lastly, all the selected indicators are synthesized in a aggregated index of sustainability. All these steps are extensively described below.

A brief description of principal components analysis

PCA is a statistical multivariate methodology used to study large sets of data. This method reproduces a great proportion of variance among a big number of variables by using a small number of new variables called principal components (PCs). The PCs are linear combinations of the original variables, and the analysis of multidimensional data is simplified when these are correlated (Judez, 1989). The first PC explains maximum variance between data, while the second component is a new combination of the original variables being orthogonal to the first component and explaining the second largest value of variation among observations, and so forth. The absorption of variance in each component is computed with the so-called eigenvalues. One property of the PCs is that they are uncorrelated between them, and then each component is measuring a different dimension in the data.

High absolute values of loadings of the variables (i.e. indicators) on the PCs imply that the indicator has a large bearing on the creation of that component. Thus, the most important indicators in each component, that best explain variance; will also be more useful in explaining variability between observations (i.e. countries). Each component will be a linear combination of indicators (variables) multiplied by their loadings on that component. Observations (countries) will have coordinates in each axis or component, computed with the standardized value of each variable (zero mean and unit variance) for that observation using the linear combination of variables with PCs obtained in the analysis.

Apple trade in Spain

Twenty most important apple exporters of the world and other 16 countries that have exported apples to Spain in the last 10 years have been selected as the observations set. Data of apple exports and imports are from FAO (2008). The 36 selected countries are shown in Tab. 3.

Environmental indicators

The environmental dimension was analysed considering the crop production and the transport of the apples. Agricultural practices were assessed searching information about fertilization, irrigation and yield of apple orchards, i.e. FAOSTAT (FAO, 2008), International Fertilizer Industry Association (IFA, 2008) and Water Footprint of Nations (Waterfootprint, 2008). The agricultural impact was calculated for 1 hectare (ha) of orchard and for 1 kilogram (kg) of fresh apples (just dividing by yield). Irrigation impact was considered as the water requirements of the crop for one year (Waterfootprint, 2008) in m^3 per ha or per kg of apple. Fertilization impact was assessed by computing emissions and inputs during manufacturing of fertilizers, so data per kg N, kg P_2O_5 and kg K_2O manufactured were used. A nutrient balance was carried out in apple orchards, considering atmospheric N emissions from fertilizers (NH_3, N_2O and NO) with EMEP methodology (EEA, 2004) and nitrate leaching as the mean of a constant value of 16% of N inputs in fertilizers (Neilsen and Neilsen, 2002) and the result of the balance $N_{leaching} = N_{fertilizers} - N_{crop\ uptake} - N_{gaseous\ emissions}$, when it was positive. The inventory of transport was done with the distance from production zones to Madrid (Spain) and using lorry and ship emissions per t km transported. Road transport by lorry was considered from countries in continental Europe and distance was computed by data from ViaMichelin (2008). Sea transport by ship was considered from the other countries, computing distance from the main port of the country to Algeciras or Valencia in Spain (the two main ports for fruit trade), via Panama, Suez or Gibraltar (Sea Distances, 2008). Lorry transport from the ports to Madrid was also taken into account. Life cycle analysis of transport data was done for 1 kg of fresh apples from each country.

Ten impact categories were considered: global warming, acidification, eutrophication, human toxicity, ecotoxicity in fresh water, photochemical oxidants formation, energy use, water resources use, abiotic resources depletion and land use. Characterization factors for each category were use from CML-IA (2004). World in 1995 normalization factors were used (Van den Berg *et al.*, 1995; Huijbregts *et al.*, 2003; CML-IA, 2004).

Normalized values of the LC analysis of each impact category were added up for crop production (LCAcrop indicator) and for transport (LCAtransport indicator), and the sum of those two was an overall potential environmental impact indicator (LCAtotal). Other two indicators were calculated considering a local and a global geographical scale. The impact of apple production over local population and ecosystems was calculated per ha of cultivated land, considering that the main impact categories were toxicity for human population, depletion and pollution of water resources and land use and occupation for agriculture. A multi-criteria analysis was carried out using analytical hierarchy process (AHP) (Saaty, 1990). The ten studied impact categories were ranked in a sequence from more to less relative importance at local scale: Human toxicity = water resources use = eutrophication = ecotoxicity fresh water = land use > acidification = photochemical oxidants formation > energy use = abiotic resources depletion > global warming. Based on these assumptions, the respective weights for each of the ten impact categories were calculated according to the AHP procedure. These weights were applied to the crop LC analysis and a local impact indicator was considered (LCAlocal).

The global impact of apple production and trade was calculated per kg of apple, considering that the main impact categories were climate change, energy use and depletion of natural resources. An AHP analysis was carried out sorting the ten impact categories in a sequence from more to less relative importance at global scale: Global warming > energy use = abiotic resources depletion = land use > water resources use = eutrophication = ecotoxicity fresh water > acidification > human toxicity > photochemical oxidants formation. The weights were calculated as for the local scale and they were applied to the crop and transport LC analysis and a global impact indicator was considered (LCAglobal).

Other environmental indicators were also calculated pertaining to particular aspects of environmental impacts, as productive land requirements, use of resources or emissions during the apple life-cycle. Ecological footprint was determined considering the yield of the orchards and the CO_2 emitted during fertilizers manufacturing and apple transport. Arable land and sink forest land for CO_2 were calculated and equivalence factors (Wackernagel *et al.*, 1999) were applied to determine the ecological footprint, i.e. m^2 of land required per kg of apples. Carbon footprint was computed as the kg of CO_2 equivalent per kg of apples emitted during cultivation and transport. Water footprint was calculated considering the yield and the water requirements in each country (m^3 ha^{-1}) in L of water per kg of apples. Energy footprint was determined as the energy used in fertilizer manufacturing and apple transport (MJ kg^{-1}). Reactive nitrogen released to the biosphere during fertilization and NO_x emitted in fertilizer industries and apple transport were also calculated (g N kg^{-1}).

A synthetic environmental indicator was calculated by PCA using a matrix of 18 variables x 36 countries. The initial set of environmental indicators included a large set of variables in order to firstly investigate which of them showed higher variability within the studied observations and correlation within them, that is strength of PCA, although some of them should explain redundant information. Thus, fertilization rates (kgN/ha, kgP/ha and kgK/ha), fertilizers per unit of apple produced (kgN/kg, kgP/kg and kgK/kg), water requirements (m^3/ha), water footprint (L/kg), transport distance (km), ecological footprint, energy footprint, carbon footprint, reactive nitrogen, and LCA values (LCAcrop, LCAtransport, LCAtotal, LCAglobal and LCAlocal) were included. Before developing the PCA, all the variables were signed as positive or negative in order to make them unidirectional (Jha and Murthy, 2003). PCA was performed with STATGRAPHICS software, standardizing data to zero mean and unit variance. Eigenvalues and the amount of variance explained by each principal component (PC) were calculated. The number of components retained in the analysis was assessed by Cattel's scree plot, which indicates that we should retain i components because, after the i+1 component, the plot becomes flat, corresponding to eigenvalues lower than one. The value of the eigenvectors and loadings of variables with PCs were computed. Coordinates of each country with each axis were determined. The aggregation of data into a single environmental sustainability index was calculated as:

$$PCA_{environmental}(i) = \frac{\sum_{k=1}^{j} F_{ki}\sqrt{\lambda_k}}{\sum_{k=1}^{j} \sqrt{\lambda_k}} \qquad i = 1,...,36(countries) \qquad [1]$$

Where, F_{ki} is the coordinate of the country i in the component k (and j components are retained) and λ_k is the eigenvalue of the component k. This index should give information about the relative value of environmental sustainability between the studied countries, taking into account that LCA gives an estimation of potential impacts.

Economic indicators

Economic dimension was analysed considering micro and macro economic aspects of apple trade. Micro economic level was studied at farm scale, so productivity, yield stability and yield sustainability were calculated as fundamental properties of farming systems (Marten, 1988). These indicators were computed as Tab. 1 shows. Macro economic level was assessed by nine indicators. One studied aspect was the positive effects of exportation of agricultural products as the returns obtained by apple exports, with a high market share and competitiveness. On the other hand, some negative aspects would arise as market oligopoly with an export-oriented farming with apple cultivation as a monoculture. Other negative factors could be the decay of exportation prices (Barriga, 2003) or the decreasing and abandonment of apple cultivated area. Other interesting indicator is called globalization in the sense that in some countries a great volume of imports and, at the same time, exports of apples exists, so the national market is decidedly open to the global market. All the statistical data were obtained from FAO (2008).

A synthetic economic index was calculated by PCA using a matrix of 12 variables x 36 countries (Tab. 1). All the variables were signed as positive or negative in order to make them unidirectional (Jha and Murthy, 2003). PCA was performed as described above and the aggregation of data into a single economic sustainability index ($PCA_{economic}$) was computed as in equation [1].

Tab. 1: Initial set of economic and social indicators used in the analysis.

Economic dimension	
Indicator	Calculation
Productivity	Average yield of apple in the period 1996-2003.
Yield stability	Coefficient of variation of apple yield during 1996-2003.
Yield sustainability	s_i/Y_i; where: s_i: slope of yield over the period 1996-2003 in country i. Y_i: average yield in country i during that period.
Exports value	$(AEV_i/AgEV_i)$*100; where: AEV_i: average apple exports value in country i in 2000-05 period. $AgEV_i$: average agricultural exports value in country i in 2000-05 period.
Market share	(AEC_i/AEW)*100; where: AEC_i: apple exports in country i over the period 1996-2004. AEW: total apple exports during that period in the world.
Competitiveness	Es_i/E_i; where: Es_i: slope of apple exports in country i over the period 1996-2004. E_i: average exports in country i during that period.
Oligopoly	MS_i-AMS; where: MS_i: market share of country i. AMS: average market share of each country if all world exports where fairly distributed.
Export-oriented farming	(AEA_i/TAA_i)*100; where: AEA_i: area of exported apples in country i in the period 1996-2004. TAA_i: total area of apple in country i in the period 1996-2004.
Monoculture	(AA_i/TFA_i)*100; where: AA_i: area of cultivated apples in country i in the period 1996-2004. TFA_i: total fruit cultivated area in country i in the period 1996-2004.
Exports price	Slope of apple exports prices over the period 1996-2004 in each country.
Abandonment apple area	Slope of apple cultivated area over the period 1986-2006 in each country.
Globalization	$[(AI_i+AE_i)/AP_i)]$*100; where: AI_i: apple imports in country i in the period 1996-2004. AE_i: apple exports in country i in the period 1996-2004. AP_i: apple production in country i in the period 1996-2004.
Social dimension	
Indicator	Calculation
Income stability	Coefficient of variation of orchard income (yield x price) during 1996-2003.
Income trend	Slope of income over the period 1996-2003.
International justice	APP_i-APP_{av}; where: APP_i : apple producer prices in country i during 1996-2003. APP_{av}: apple producer prices of the major 20 exporting countries during that period.
Market-farmer equity	(APP_i/ACP_{Sp})*100; where: APP_i: apple producer price in country i during 1996-2003. ACP_{Sp}: apple consumer price in Spain in 2007/08.
Fruit deficit	FVC_i-$FVCR_{WHO}$; where: FVC_i: fruits and vegetables consumption per capita in country i in the year 2003. FVC_{WHO}: fruits and vegetables consumption recommended by WHO (400 g day^{-1}).
Fruit diversity	Shannon index of fruit consumption per capita in year 2003.
Food waste	AW_i/AS_i; where: AW_i: apple waste in country i in year 2003. AS_i: apple supply in country i in year 2003.
Own supply	AS_i/FVC_i; where: AS_i: apple supply per capita in country i in year 2003. FVC_i: fruits and vegetables consumption per capita in country i in year 2003.

Social indicators

Social dimension was analysed considering farm level and society level. Farm level was assessed with four indicators and, first of all, farm income stability and income trend were calculated (Tab. 1). Market-farmer equity calculates the percentage of the final price (paid by consumer for 1 kg of apples) that farmers receive. International justice was also computed as the difference in revenues between apple in one country and average revenues from apples of the 20 major apple exporting countries (Wurtenberger *et al.*, 2006). Social aspects are related to fruits and vegetables deficit in the diet from the minimum recommended by World Health Organization (i.e. 400 g capita^{-1} day^{-1}) and diversity of types of consumed fruits. Other social aspects are food waste and own supply of apples. All the statistical data were obtained from FAO (2008), except apple price paid by consumers in Spain (MAPA, 2008).

A synthetic social index was calculated by PCA using a matrix of 8 variables x 36 countries (Tab. 1). All the variables were signed as positive or negative in order to make them unidirectional (Jha and Murthy, 2003). PCA was performed as described above and the aggregation of data into a single social sustainability index (PCA_{social}) was computed as in equation [1].

Sustainability index

A synthetic sustainability index was built up considering environmental, economic and social indicators studied in the previous sections. Eleven environmental indicators were selected from the initial set of 18, considering those that showed a high correlation coefficient with the $PCA_{environmental}$ aggregated index, discarding also those that gave redundant information (e.g. fertilization rates or LCA_{total} indicator). The same procedure was carried out to select 9 economic and 8 social indicators. PCA was performed using a matrix of 28 variables x 36 countries. Aggregation was done as showed in equation [1] and a $PCA_{sustainability}$ index was computed.

Results and discussion

Principal components analysis for the environmental indicators is shown in Tab. 2. Five principal components were retained and they explained 93.5% of the total variance of the data. The first component (PC1) is highly correlated with five indicators that describe ecological footprint (EF), water footprint and LCA results for crop, total system and global scale. These indicators are related to yield and water consumption of apple orchards. The second PC is correlated with LCA in transport and related indicators as carbon and energy footprints and distance covered. PC3 is correlated with nitrogen and potassium fertilization, PC4 with impacts at a local level (per ha) and PC5 with phosphorus fertilization.

These indicators will explain with good agreement the differences in environmental sustainability between countries, and the coordinates of each country with each component will built up the synthetic environmental index, weighted with the eigenvalues of each component. The resulting index for each country and the corresponding ranking between all, are shown in Tab. 3. Twenty countries show positive values, thus higher than the mean (that is zero). The other 16 countries show negative values. France, Netherlands, Belgium and Switzerland are in the best positions in the relative hierarchy of environmental sustainability, while China, Cyprus, Iran and Korea are in the lower part of the ranking.

Another five principal components were retained in the analysis of the economic dimension (Tab. 2). The first PC would be defined as international trade, as it is positively correlated with market share and the subsequent revenues from exports, and negatively with market oligopoly. The economic sustainability index is positive in 17 countries and the other 19 show values under the mean. The first positions in the relative ranking are held by Chile, USA, Italy and France, while Finland, Latvia, Cyprus and Morocco are located in the last positions.

Social indicators were explained by four PCs. The first PC shows high loadings with market-farmer equity and international justice related to apple prices, and with food waste. The second PC is highly correlated with farm income and fruit deficit in population's diet. Regarding the aggregated social index ranks Cyprus, UK and Switzerland in the first positions of the 25 countries with positive value, while 11 show negative values as Moldova, Chile and Latvia that show the lowest values.

Tab. 2: Principal component analysis for environmental, economic, social and sustainability indices.

Environmental indicators

PCs retained	PC1	PC2	PC3	PC4	PC5
Eigenvalues	7.34	4.41	3.00	1.84	1.18
Variance absorption (%)	38.6	61.8	77.6	87.3	93.5
Correlated indicators (loadings)	EF (0.95) LCAcrop (0.94) WaterF (0.94) LCAtotal (0.93) LCAglobal (0.91)	LCAtransport (0.99) EnergyF (0.96) CarbonF (0.95) Distance (0.87)	kgK/ha (0.92) kgK/kg (0.91) kgN/kg (0.73) kgN/ha (0.67) Nreactive (0.63)	LCAlocal (0.96) m^3/ha (0.96)	kgP/ha (0.88) kgP/kg (0.85)

Economic indicators

PCs retained	PC1	PC2	PC3	PC4	PC5
Eigenvalues	3.44	1.90	1.60	1.30	1.10
Var. absorption (%)	28.6	44.5	57.8	68.6	77.4
Correlated indicators (loadings)	Oligopoly (-0.95) Market share (0.95) Exports value (0.60)	Yield sustainability (0.82) Globalization (0.82) Yield stability (0.60)	Exports price (0.80) Abandonment (-0.69) Competitiveness (0.66)	Ex. oriented (-0.83) Productivity (0.82)	Monoculture (0.91)

Social indicators

PCs retained	PC1	PC2	PC3	PC4
Eigenvalues	2.18	1.70	1.18	1.00
Var. absorption (%)	27.3	48.5	63.2	75.8
Correlated indicators (loadings)	Equity (-0.95) Int. justice (0.72) Food waste (0.50)	Income trend (0.82) Fruit deficit (0.60) Income stability (0.56)	Own supply (0.92)	Fruit diversity (0.88)

Sustainability index

PCs retained	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigenvalues	6.63	5.45	3.60	2.90	1.80	1.48	1.16
Var. ab. (%)	23.7	43.1	55.9	66.3	72.8	78.0	82.2
Correlated indicators (loadings)	LCAcrop (0.94) EF (0.93) WaterF (0.93) LCAglobal (0.89) Productivity (0.80) Int. justice (0.64) Income st. (0.62) Yield st. (0.58) Exp. price (0.58)	LCAtransport (0.96) CarbonF (0.96) EnergyF (0.94) Distance (0.85) Nreactive (0.62)	LCAlocal (0.92) m^3/ha (0.92) Fruit diversity (-0.46)	Income trend (0.85) Yield sust. (0.84) Globalization (0.77) Equity (-0.57)	Market share (0.91) Oligopoly (-0.91)	Exports value (-0.83) Food waste (0.81) Export oriented farming (0.50)	Fruit deficit (0.74)

The results of the PCA for the 28 selected indicators (11+9+8) in order to develop a sustainability index are shown in Tab. 2. Seven principal components were retained and they explained 82.2% of the total variance of the original data. The first component (PC1) shows high loadings with a combination of environmental, economic and social indicators. The environmental ones were ecological and water footprints and LCA results for crop and global scale, so the main environmental issues were related to water and land use per kg of apples produced. The economic dimension was explained by two microeconomic indicators (yield productivity and stability) and one macroeconomic (trend of export prices).. Social sustainability was related to apple price indicators (international justice and farm income). The second PC is only correlated with environmental indicators related to apple transport, as LCA added values of transport, the distance covered, and the related energy consumed and equivalent carbon emitted. Moreover, reactive nitrogen emissions are captured by this second PC, although they consider the agricultural and transport phases. The third component is positively correlated with impact al local scale, mainly produced by water use per ha, and negatively with diversity in fruit diet. The last four PCs capture economic and social issues. These indicators will explain with good agreement the differences in overall sustainability between countries. The coordinates of each country with each component will built up the synthetic sustainability index for that country, weighted with the eigenvalues of each component (Tab. 3). Twenty countries show positive values of the synthetic index, and the other 16 are below the mean and show negative values in the relative ranking of sustainability performed by the analysis.

Tab. 3: Values of the aggregated indices for sustainability and environmental, economic and social dimensions of the 36 countries studied. Relative ranking of each country is also shown.

Country	$PCA_{environ}$	Ranking	PCA_{econ}	Ranking	PCA_{social}	Ranking	$PCA_{sustainability}$	Ranking
Argentina	-1.494	27	0.427	14	-0.980	31	-0.671	22
Austria	3.007	6	0.757	11	0.651	11	1.976	7
Belgium	3.523	3	1.237	9	0.400	15	2.416	4
Brazil	-0.008	21	0.367	15	-0.914	30	-0.846	24
Canada	1.819	13	-0.138	19	0.294	18	1.738	10
Chile	-0.620	25	2.789	1	-2.124	35	-1.151	26
China	-10.708	36	1.512	5	-0.733	29	-3.599	35
Cyprus	-9.614	35	-1.839	34	1.240	1	-3.476	33
Czech R.	2.875	7	-0.366	22	0.112	22	0.849	17
Denmark	1.682	15	-1.060	31	0.773	7	1.147	12
Finland	-1.799	28	-4.149	36	0.285	19	-2.314	32
France	3.875	1	1.987	4	0.147	21	2.769	1
Germany	2.061	12	0.708	12	0.373	16	0.957	16
Greece	1.428	18	-0.722	27	0.853	6	0.754	18
Hungary	-0.451	23	-0.403	23	-1.088	32	-0.684	23
Iran	-4.587	34	0.315	16	0.544	14	-2.147	30
Ireland	3.131	5	-0.524	24	0.162	20	2.183	5
Italy	2.070	11	2.284	3	0.547	13	1.934	8
R. Korea	-3.798	33	-0.189	20	0.667	10	-2.187	31
Latvia	-1.170	26	-3.804	35	-1.873	34	-3.510	34
Moldova	-2.937	32	-1.425	32	-3.063	36	-4.252	36
Morocco	-2.906	31	-1.604	33	0.065	23	-1.751	27
Netherlands	3.619	2	0.838	10	0.696	9	2.513	3
N.Zealand	-0.546	24	1.288	7	0.013	25	-0.924	25
Poland	-0.101	22	1.389	6	-1.744	33	0.221	20
Portugal	0.074	20	-0.548	25	0.623	12	0.646	19
Slovakia	2.138	10	-0.826	30	-0.207	27	-0.054	21
Slovenia	2.861	8	0.147	17	0.029	24	1.423	11
S. Africa	-2.569	30	1.240	8	-0.542	28	-1.985	29
Spain	1.690	14	-0.131	18	0.312	17	1.075	14
Sweden	0.112	19	-0.822	29	0.862	5	1.064	15
Switzerland	3.508	4	0.628	13	0.966	3	2.695	2
Turkey	1.596	16	-0.286	21	0.744	8	1.093	13
UK	2.671	9	-0.817	28	0.970	2	1.810	9
USA	1.437	17	2.357	2	0.950	4	2.096	6
Uruguay	-1.869	29	-0.614	26	-0.008	26	-1.808	28

Within the first 19 countries we can slightly separate two different groups. The first group include nine countries that show a positive value of the sustainability index and also show this positive value in the three previous computed indices pertaining environmental, economic and social sustainability. These countries show, in general, lower environmental impact in a global scale, a high productivity and a good justice for apple prices within the global market, although they have a tendency to monopolize it. This group includes USA and eight European countries: France, Switzerland, The Netherlands, Belgium, Austria, Italy, Slovenia and Germany. The second group is characterized by positive values of the aggregated sustainability index; they have a socio-environmental sustainability in the relative hierarchy ranked in the analysis, because only the environmental and social indices are positive and the economic index is negative. The environmental dimension is characterized by relative low environmental impact, particularly energy and carbon footprints, and high social sustainability, especially with regard to prices, income and waste indicators. The worse side is the low economic sustainability, represented by productivity and market share indicators. This group includes Canada, Turkey and eight European countries (Ireland, UK, Denmark, Spain, Sweden, Czech Republic, Greece and Portugal).

Another seventeen countries are in the low zones of the relative sustainability ranking established by the PC analysis. New Zealand and Iran show a positive socioeconomic sustainability index, with an important weight of apples in agricultural exports and relative good values for income and fruit consumption indicators. However, the environmental sustainability index is negative due to impacts at global scale and during the transport stage.

Argentina, Brazil, Chile, China and South Africa show a negative value of the sustainability index and reach only a positive value of the economic index. Environmental impact is relatively high for agricultural production and, above all, the transport phase due to the large distances to Spain. This impact is important at both global and local scale. Social aspects are eroded by low producer prices and deficit of fruit consumption. The economic advantages that show these countries are the market share for apples, but they tend to control it. Poland would be included with these economic sustainable countries, although it shows a positive sustainability index.

Slovakia is characterized by a positive environmental sustainability index due to global and local relative low impacts. However, economic aspects are shorted by low yield sustainability; and social dimension is deficient with regard to income trend of farmers and fruit consumption of the population. Positive social sustainability index is achieved by Cyprus, Finland, Republic of Korea and Morocco due to a relative high equity and justice in apple prices. Economic sustainability indicators as productivity and apple monoculture should be improved. The environmental impact at a global scale is another bad indicator.

The less sustainable indices are shown by Hungary, Latvia, Moldova and Uruguay. The three dimensions of sustainability show negative values and they are in the lower part of the sustainability index ranking. Productivity and monoculture should be improved in the economic dimension. Equity and justice of producer prices should be enhanced and deficit of fruits and vegetables consumption should be reduced. Environmental impact at a global scale should decrease, and ecological and water footprints should be improved.

Conclusion

Principal components analysis is a good statistical tool to develop aggregated indicators in order to asses the sustainability of apple production and trade flows in Spain. This multivariate analysis can be used as an objective approach to select the most important indicators regarding economic, social and environmental aspects of apple production and trade. The aggregation of data yields a single index easy to understand and that contains a lot of information, and allows to make a ranking between studied countries. Then, the sustainability of apple trade may be assessed by synthetic indices and strengths and weaknesses of each country may be discerned, and improvements may be suggested by studying individual indicators. The results for the main producing countries of apples imported in Spain show that France and Italy have a high sustainability index, Spain and Portugal just have positive values for the social and environmental aspects, while Argentina and Chile showed only positive values for economic sustainability.

References

Antony, G.M., Visweswara Rao, J.2007. A composite index to explain variations in poverty, health, nutritional status and standard of living: Use of multivariate statistical methods. Public Health, 121: 578-587.

Barriga Montes, I.J. 2003. Tendencia en el mercado de la manzana en los últimos 20 años. Universidad de Talca, Facultad de Ciencias Agrarias, Escuela de Agronomia, Talca, Chile, 71 pp.

Bernard, J.T., Cote, B. 2005. The measurement of the energy intensity of manufacturing industries: a principal components analysis. Energy Policy, 33: 221-233.

Castro, J.M. 2002. Indicadores de desarrollo sostenible urbano. Una aplicación para Andalucia. Ph.D. Thesis, University of Malaga, Spain, 540 pp.

CML-IA. 2004. Institute of Environmental Science, Leiden University. In: http://www.leidenuniv.nl/interfac/cml/ssp/index.html

EEA (2004). EMEP/CORINAIR Emission Inventory Guidebook. European Environmental Agency.

Escobar, L. 2006. Indicadores sinteticos de calidad ambiental: un modelo general para grandes zonas urbanas. Eure, XXXII, 96: 73-98.

FAO. 2008. FAOSTAT. In: http://www.fao.org

Huijbregts, M.A.J., Breedveld, L., Huppes, G., de Koning, A., van Oers, L., Suh, S. 2003. Normalization figures for environmental life-cycle assessment The Netherlands (1997/1998), Western Europe (1995) and the world (1990 and 1995). Journal of Cleaner Production, 11: 737-748.

IFA. 2008. International Fertilizer Industry Association. In: http://www.fertilizer.org

Jha, R., Murthy, K.V. 2003. An inverse global environmental Kuznets curve. Journal of Comparative Economics, 31: 352-368.

Jollands, N., Lermit, J., Patterson, M. 2004. Aggregate eco-efficiency indices for New Zealand – a principal component analysis. Journal of Environmental Management, 73: 293-305.

Judez, L. 1989. Tecnicas de analisis de datos multidimensionales: bases teoricas y aplicaciones en la agricultura. MAPA, 301 pp.

Levitan, L. 2000. “How to” and “why”: assessing the enviro-social impacts of pesticides. Crop Protection, 19: 629-636.

MAPA. 2006. Hechos y cifras sobre la agricultura. Ministerio de Agricultura, Pesca y Alimentacion. Secretaria General Tecnica, Madrid, 159 pp.

MAPA. 2008. Precios semanales en la cadena de comercializacion manzana. MAPA, 2 pp.

Marten, G.G. 1988. Productivity, stability, sustainability, equitability and autonomy as properties for agroecosystems assessment. Agricultural Systems, 26: 291-316.

Neilsen, D., Neilsen, G.H. 2002. Efficient use of nitrogen and water in high-density apple orchards. HortTechnology, 12: 19-25.

Rodriguez-Diaz, J.A., Camacho, E., Lopez-Luque, R., Perez-Urrestarazu, L. 2008. Benchmarking and multivariate data analysis techniques for improving the efficiency of irrigation districts: An application in Spain. Agricultural Systems, 96: 250-259.

Saaty T.L., 1990. How to make a decision: the analytic hierarchy process. European Journal of Operational Research; 48: 9-26.

Sands, G.R., Podmore, T.H. 2000. A generalized environmental sustainability index for agricultural systems. Agriculture, Ecosystems and Environment, 79: 29-41.

Sea Distances. 2008. Sea distances – Voyage calculator. In: http://e-ships.net

Soler-Rovira, J., Arroyo-Sanz, J.M. 2003. Spatial and temporal trends of environmental indicators relating to nitrogen and phosphorous in Spain. In: Schnug, E. *et al.* (eds). Fertilizers in context with resource management in agriculture. 14th International Symposium of Fertilizers. Hungary, pp: 321-329.

Soler-Rovira, J., Arroyo-Sanz, J.M. 2004. Organic nutrient management indicators at district level in Spain. In: Hatch, D.J. *et al.* (eds). Controlling nitrogen flows and losses. Wageningen Academic Publishers, The Netherlands, pp: 231-233.

Van den Berg, N.W., Dutilh, C.E., Huppes, H. 1995. Beginning LCA: A guide into environmental Life Cycle Assessment, Center for Environmental Science (CML), Leiden.

ViaMichelin. 2008. ViaMichelin. In: http://www.viamichelin.es

Wackernagel, M., *et al*. 1999. National natural capital accounting with the ecological footprint concept. Ecological Economics, 29: 375-390.

Waterfootprint. 2008. Water footprint network. In: http://www.waterfootprint.org

Wurtenberger, L., Koellner, T, Binder, C. 2006. Virtual land use and agricultural trade: Estimating environmental and socio-economic impacts. Ecological Economics, 57: 679-697.

Yu, C., *et al.* 1998. Effective dimensionality of environmental indicators: a principal component analysis with bootstrap confidence intervals. Journal of Environmental Management, 53: 101-119.