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Making Sustainability Rankings Using Compromise Programming. An Application to European Paper Industry

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This paper characterizes the sustainability of the European paper industry. To undertake this task the sustainability of each country is defined by using fourteen indicators of a diverse nature (economic, environmental and social). These indicators are aggregated into a composite or synthetic index with the help of a compromise programming model. In order to associate different weights with each indicator, a survey among international experts has been carried out. In this way, a ranking of seventeen European countries analysed in terms of the sustainability of the European paper industry has been established, where Finland is the most sustainable paper industry in Europe except when the most balanced solution is chosen. Also, the results are robust when different preferential weights are attached. Finally, this methodology can be applied at a more disaggregated level and other indicators can be introduced.

Keywords compromise programming, indicators, sustainability, paper industry
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1 Introduction

Since the consolidation of the Summit of Río, held in 1992, the idea of sustainability has been spreading not only to fields associated with the management of natural resources, but also to applications in industry (Singh et al. 2007), in energy (Zhou et al. 2007), in tourism (Blancas et al. 2010) or in agriculture (Gómez-Limón and Sánchez-Fernández 2010).

Sustainability has been dealt with from several angles, although there is a certain consensus in that it can be approached by defining an initial set of indicators. Namely, this abstract concept is specified by adequately defining a pluridisciplinary list of acceptable criteria and indicators (Raison et al. 2001), which cover aspects that are assumed to be integrated into the idea of sustainability. On the other hand, the term "sustainability" is easy to understand intuitively, although it is not at all easy to conceptualise, to measure or to formalize rigorously. Besides, from an entrepreneurial perspective, the concept of sustainability is more questionable. In fact, from a business perspective, sustainability on many occasions is linked to components related to competitiveness, innovation and the marketing of companies. Thus, with this combination of ideas a certain company is able to differ from its competitors in order to improve its economic performance.

The main purpose of this study is to analyse the sustainability of the paper industry at a European level using a set of indicators. In fact, sustainability here is analysed in relative terms. With the methodology proposed, a benchmarking tool for comparing the sustainability of paper industry in Europe was obtained. Thus, we have defined a set of indicators that permit the characterization of the managerial reality of the paper industry in each country analysed under sustainability terms. The proposed approach has been applied to the paper industries of a significant number of European countries. To undertake this task, the methodology used has been based on a compromise programming model with binary variables. NACE[1] 21 industries have been adopted in this study. This product classification has been used in other wood-based industry studies (e.g., Stendahl 2009). NACE 21 includes the manufacture of pulp, paper and converted paper products. The manufacture of these products is grouped together since they constitute a series of vertically connected processes.

There are few papers explicitly dealing with this topic in the wood-based industry. One exception to this trend is the work of Hart et al. (2000), in which different cases corresponding to multinational firms were analysed. They mainly focused on qualitative aspects, related to how some of these firms managed their forests. A similar approach can be found in Johnson and Walck (2004), who described five criteria necessary for integrating sustainability into forest industries. The number of papers analysing comparatively rankings of countries in terms of the level of sustainability of their respective wood-based industries is somewhat scarce (Ojala et al. 2006). In most cases, this type of work is orientated towards the compilation of statistical data or to the formulation of models with the purpose of explaining several aspects associated with the production and consumption of forest products (Buongiorno et al. 2003). Besides, we would like to point out that our paper does not research the relationships in terms of sustainability of the forest management with forest-based industries (see Östlund and Roome 1998, Korhonen et al. 2001, among other works). Finally, it should be noted that the analysis of various aspects regarding wood-based industries using multi criteria techniques is a well-established topic in the literature (Diaz-Balteiro and Romero 2008). In Nyrud and Baardsen (2003) or Lähtinen et al. (2008), there are examples of the application of these methodologies to problems in these industries.

In relation to the methodology employed, many studies focus exclusively on the analysis phase, i.e. describing and measuring a set of previously defined indicators, without going on to the phase of explicitly aggregating the indicators cited. With this in mind, and concentrating on the forestry context, numerous studies on sustainability have been published but all of them fall short in some aspects; it is assumed that the indicators cannot be aggregated, or, if they are, the aggregation rule is introduced in a rather mechanistic way.

[1] NACE is the acronym for "Nomenclature statistique des activités économiques dans la Communauté européenne"[Statistical classification of economic activities in the European Community].

In other cases, it is also supposed that the same weight is conferred to each indicator (Carabelli et al. 2007). However, the assumption of equal weights is rather unrealistic, since the importance attached by a decision-maker to each indicator can be different. For that reason, in this work an extensive survey has been made among international experts with the aim of justifying the conferring of different weights to each of the indicators selected.

In the next Section, it is demonstrated how the use of multicriteria tools to tackle sustainability problems is widely documented in the literature. After that, it will present the compromise programming methodology. Section 4 introduces the case study, embracing 17 European countries. Section 5 shows the results of the paper and, finally, the main conclusions derived from the research, as well as possible further extensions, are presented in the last section.

2 Sustainability Indicators and MCDM Methods

In view of multidimensionality being intrinsic to the sustainability concept, many works have attempted to characterize this term by falling back on multicriteria techniques (from now on the acronym MCDM (Multiple Criteria Decision Making) will be associated with the word "multicriteria"). In the forestry sphere this fact can be verified by referring to the review work published by Diaz-Balteiro and Romero (2008). Continuing in the forestry context, works like those of Mendoza and Prahbu (2000a,b), Mendoza and Dalton (2005) or Babaie-Kafaky et al. (2009) recommend the use of discrete MCDM methods, like the Analytical Hierarchy Process (AHP), in order to evaluate sustainability. Vacik et al. (2007), to characterize the sustainability of possible forest management alternatives, employ the Analytical Network Process (ANP), the enlarged version of the AHP. This comparison between AHP and ANP for approaching sustainability in forest management by means of a set of indicators can also be seen in the works of Wolfslehner et al. (2005) and Wolfslehner and Vacik (2008, 2011). Other authors (Mendoza et al. 2002, Mendoza and Prabhu 2003) suggest using MCDM qualitative methods for the integration of criteria and indicators in order to evaluate sustainability. Going on with discrete MCDM methods, Bousson (2001) applies the ELECTRE (Elimination and (et) Choice Translating Algorithm) method to select the best management alternative subject to certain criteria, while in Balana et al. (2010) several MCDM methods are compared to evaluate the sustainability in communal forests in Ethiopia. Huth et al. (2005), for these purposes, use the PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluations) method.

Similarly, Ducey and Larson (1999) apply a methodology which hybridizes the multicriteria techniques with approaches based on the fuzzy theory in order to evaluate the sustainability of some decisions relative to forest management. On another methodological line, Kangas et al. (1998) have recommended the use of multiattribute techniques to carry out this indicator aggregation process. Other authors combine these tools by integrating a spatial component into the analysis, as can be observed in the work of Store (2009). In relation to the continuous MDCM methods, in Diaz-Balteiro and Romero (2004a,b) a methodology based on goal programming is proposed to aggregate the sustainability indicators in an acceptable way. Maness and Farrell (2004) apply a multi-objective optimization with fuzzy sets in order to aggregate different criteria and indicators. Finally, Voces et al. (2010) address a problem of sustainability in the European paper industry by resorting to a "satisficing" logic that leads to goal programming formulation, whereas in this paper we resort to an "optimization" approach through a composite compromise programming.

3 Methodology

Let us introduce the following general scenario. We have $i=1,2,...n$ countries, each one is evaluated according to $j=1,2,...m$ sustainability indicators. The key question is to obtain a cardinal "ranking" of the n countries in terms of aggregate sustainability. We shall undertake this task by adapting a procedure proposed by Diaz-Balteiro and Romero (2004 a, b) from a "satisficing" context to an "optimizing" scenario. The first step of the procedure will consist of defining *n*x*m* outcomes R_{ij}, that measure the value reached by the *i*th country when it is evaluated according to the *j*th sustainability indicator. Given that, normally, sustainability indicators are measured in different units and their absolute values might differ considerably, their straightforward aggregation (e.g., a weighted sum of indicators) has no meaning. In order to avoid this type of problem, the following normalization system is proposed:

$$\bar{R}_{ij} = 1 - \frac{R_j^* - R_{ij}}{R_j^* - R_{*j}} = \frac{R_{ij} - R_{*j}}{R_j^* - R_{*j}} \quad \forall i,j \qquad (1)$$

where $\bar{R}_{ij}$ is the normalised value reached by the *i*th country when it is evaluated according to the jth indicator. It should be noted that R_j^* is the optimal or ideal value for the *j*th sustainability indicator. This ideal value represents the maximum value if the indicator is of the type "more is better" or the minimum value if the indicator is of the type "less is better". In the same way, R_{*j} is the worst value or anti-ideal value for the jth sustainability indicator; that is, the minimum value if the indicator is of the type "more is better" and the maximum value if the indicator is of the type "less is better". With this normalization system, the indicators do not have any dimension and they are all them bounded between 0 and 1; that is, from the worst to the best of the criteria values according to a local scale. Moreover, for this normalization system the ideal vector for the normalized values is $\bar{R}^* = (1,1,\ldots 1)$ and the anti-ideal vector $\bar{R}_* = (0,0,\ldots 0)$.

Let us introduce parameters such as α_j that are weights measuring the relative importance attached by an expert or by a panel of experts to the *j*th indicator of sustainability with respect to the other indicators. Finally, binary variables X_i are introduced into the analysis. We will see below how if $X_i = 1$ the *i*th country is chosen, otherwise $X_i = 0$. With this ingredient, we can formulate the following general binary compromise programming model (Yu 1973, Zeleny 1974):

$$\text{Min } L_p = \sum_{i=1}^{n} \sum_{j=1}^{m} \left[\alpha_j (1 - \bar{R}_{ij}) X_i \right]^p$$

Subject to:

$$\sum_{i=1}^{n} X_i = 1 \qquad (2)$$

$$i \in \{1,2,\ldots n\} \; j \in \{1,2,\ldots m\}$$

$$X_i \in \{0,1\}$$

where *p* is the metric defining the L_p family of distance functions. In short, model (2) minimizes the topological distance between the achievement of the generic *i*th country in the *m* indicators considered with respect to the unit vector (1,1,…1) that represents the ideal values for the *m* indicators. Thus, by solving (2) the "most sustainable" country will be obtained. By solving model (2) in an iterative way we can also obtain the ranking of the *n* countries in terms of aggregate sustainability. Thus, we only need to attach value 0 to the X_i decision variable corresponding to the "most sustainable country". Accordingly, after solving model (2) $n-1$ times with the incorporation into each computer run of an additional constraint such as $X_i = 0$ (when the *i*th country is the most sustainable one), then the optimal values of the objective functions will provide the aggregate index of sustainability attached to each one of the *n* countries considered.

From the numerable infinite models underlying (2), two interesting models with a clear preferential interpretation for the problem analysed will be derived. First, the model corresponding to metric $p = 1$. For this, metric model (2) turns into the following binary linear programming model:

$$\text{Min } L_1 = \sum_{i=1}^{n} \sum_{j=1}^{m} \left[\alpha_j (1 - \bar{R}_{ij}) \; X_i \right]$$

Subject to:

$$\sum_{i=1}^{n} X_i = 1 \qquad (3)$$

$$i \in \{1,2,\ldots n\} \; j \in \{1,2,\ldots m\}$$

$$X_i \in \{0,1\}$$

Model (3) implies a minimum average disagreement; that is, for this particular model, by applying the iterative procedure mentioned above, we will obtain the ranking of countries in terms of the maximization of the weighted sum of normalised sustainability indicators. This solution is an appealing one since it provided the best aggregate performance. However, for this solution extremely poor results for one of the indicators can be obtained, which might be unacceptable in terms of sustainability.

For metric $p=\infty$, model (2) turns into the new following binary linear programming model (Romero 1991):

$$\begin{aligned}
&\text{Min } L_\infty = D\\
&\text{Subject to:}\\
&\sum_{j=1}^{m}\alpha_j(1-\bar{R}_{ij})X_i \le D \quad i\in\{1,2,...n\}\\
&\sum_{i=1}^{n}X_i=1\\
&i\in\{1,2,...n\}\ j\in\{1,2,...m\}\\
&X_i\in\{0,1\}
\end{aligned}\tag{4}$$

where D represents the maximum deviation or disagreement. In this way, the deviation or disagreement with respect to the ideal of the most displaced indicator is minimised. Thus, the “most balanced” sustainable country is obtained. Again, by solving iteratively model (4) as explained above, we will obtain the ranking of countries in terms of maximum equilibrium or balance. Again, this solution is appealing due to its balanced character, but this type of solution can produce a poor “average” result, which might be unacceptable.

To deal with this conflict between “average” versus “balance”, we can trade-off the L_1 with the L_∞ compromise programming models, through the formulation of the following binary composite programming model (André and Romero 2008):

$$\begin{aligned}
&\text{Min } L_\lambda=(1-\lambda)D+\lambda\sum_{i=1}^{n}\sum_{j=1}^{m}\left[\alpha_j(1-\bar{R}_{ij})X_i\right]\\
&\text{Subject to:}\\
&\sum_{j=1}^{m}\alpha_j(1-\bar{R}_{ij})X_i \le D \quad i\in\{1,2,...n\}\\
&\sum_{i=1}^{n}X_i=1\\
&i\in\{1,2,...n\}\ j\in\{1,2,...m\}\\
&X_i\in\{0,1\} \quad \lambda\in[0,1]
\end{aligned}\tag{5}$$

where λ plays the role of a control parameter. Thus, when $\lambda=1$ model (5) turns into model (3), and when $\lambda=0$ model (5) turns into model (4). For values of control parameter λ belonging to the open interval (0,1), intermediate solutions between the L_1 and the L_∞ can be obtained if they exist. Therefore, control parameter λ trades-off “average” versus “balance” solutions, allowing us to determine best-compromises among these desirable but usually opposite criteria.

4 Case Study: European Paper Industry

In order to define the sustainability of an industry or of a group of industries, it is necessary to measure different types of indicators: economic, social, environmental, etc. Nowadays, it is essential to link sustainability at the entrepreneurship level not only to the existence of the firm as a simple supplier of goods with a market value, but also to another group of attributes (social, environmental) that can provide it with a higher value added as a function of the consumers’ perceptions. In the last few years, these intangible attributes have been integrated into expressions like “corporate social responsibility”.

Although we have incorporated all these attributes into this study, the industrial nature of the activities considered imposes the prevalence of economic indicators. Also, the scant level of the disaggregation of environment information, which still awaits an adequate treatment, should be underlined. In fact, no other potential environmental indicators in the paper industry have been included due to their data not being disaggregated at the paper industry level. In short, fourteen indicators encompassed in the above perspectives have been selected and are shown in Table 1. In this way, we aimed to include the different aspects of the value chain of the European paper industry which determine a greater or lesser sustainability. The selection of these indicators was conditioned, firstly, by the information available at a European level. The statistical sources used, such as Eurostat databases, are mainly of an international nature. Similarly, United Nations statistical data of wood products and international trade have been used because the paper industries are integrated into these databases. Nevertheless, when necessary, different National Statistical Offices have been consulted.

Next, we have analysed the meaning of the fourteen indicators selected, which can be classified into two classes or categories: “less is better”, or “more is better”, since a reduction or an increment in the indicators’ values supports the sustainability of the industry. The first indicator selected was the *gross value added* as a percentage with respect to the paper industry in the manufacturing sector. It constitutes an indicator that shows the relative weight of this industrial sector in the total manufacturing activity of each country. It has been considered that a reduced contribution of the value added implies a reduced allocation of resources compared to other more productive and dynamic industrial sectors. Regarding *energetic efficiency*, this indicator represents a marginal cost, because it covers the amount of energy that it is necessary to buy in order to obtain an additional metric ton of product. Logically, a greater sustainability is reached when the value of this indicator is a low one. The third indicator, *dependence on industrial roundwood*, gives valuable information about the different national market strategies for this input, and it is defined by the quotient between imports and apparent consumption. It should be remembered that the latter is equal to the sum of national production plus the imports less the exports.

On the other hand, the following indicators present, direct or indirectly, labour use as a production factor. Thus, the *unitary average wage* indicator shows workers’ earnings for this industrial sector in each country. Without analysing the differences associated with the national income per capita, a higher value of this indicator is considered as being more sustainable from a social point of view. Conversely, the *gross value added per employee* shows an approach to the traditional “labour productivity” concept. Finally, the *intensity in the labour force* (percentage of labour costs in total production) gives information on the intensity in the use of labour as a production factor for the paper industry in each country. The more traditional sectors, of a lesser complexity and vitality, also use this factor more intensively. For that reason, in this study it was preferable for this indicator to reach its lowest possible value.

The *investment rate* provides information on the intensity in the use of the capital factor for this industry in each country, measured as the quotient between investment and value added at factor cost. Next, we show four indicators related to innovation. First, it has been considered to be appropriate to incorporate the *acquisition of built-in technology* into this group of indicators, because this is the principal way to incorporate innovation, mainly in small and medium-sized firms. The second indicator in this group, the percentage of *innovative firms* with respect to the total number of firms, shows the penetration rate of innovative activities in the paper industry. Also, the percentage of the total turnover of the paper industry in each country due to innovative firms is another indicator of the importance of innovation in paper industries (*effects of the innovation*). Finally, the number of *patents applications* to the European Patent Office in the reference year (2004) is a widely used indicator of the output due to the innovative activities developed in each country, and it has been used in this research. These indicators have been considered as belonging explicitly to the category “more is better”, since the higher the figures, the more the paper industry will be sustainable. This is because it is usually recognized that a good way to achieve a greater sustainability of firms could be by increasing the results associated with the research and development (Paech 2005).

A complementary indicator selected could be the *external competitiveness* (Balassa index). This has been defined as the relationship between the importance of the exports of a certain industrial sector with respect to the total industrial exports in a particular country, and, over a wider area that might be the whole world, Europe, or, in this case, the cluster of European countries analysed. It represents an external competitiveness indicator, and if this index has a larger value than the unit, a competitive advantage does exist, or, in a contrary sense, it does not.

Finally, in this investigation we included two indicators related to some environmental characteristics of these firms. First, the *waste* generated by them gives information on the pollutants produced by their industrial activity. To allow a comparison between the different countries, this figure is divided up between the added value corresponding to each specific paper industry. It has been assumed that "less is better", because, in this way, the sustainability of these firms increases. The last indicator in Table 1 shows the quotient between the total current *expenses for environmental protection* and the number of employees. Here, only the expenditure on environment protection that exclusively affects the period in which it was incurred, without any future economic projection, will be included. For the purpose of comparing the different figures corresponding to the European countries included in this analysis, this value is distributed between the number of employees.

It was aimed to apply these indicators to the forest industry of all the EU countries. However, in certain countries, there was no information available for one or several indicators. In those cases it was opted to remove those countries from the analysis. In the end, data corresponding to 17 countries were obtained. This figure is considered to be highly representative of the paper industry in Europe since, according to EUROSTAT, the turnover of these countries exceeds 88% of the total turnover of European countries (EU27). Once

Table 1. Indicators used in this study.

	Indicator	Type	Definition
1	Gross value added [%]	More is better	Gross value added of the wood-based industries respect to the gross value added of the total manufacturing.
2	Energetic efficiency [10^6 €]	Less is better	Value of purchases of energy products/Value of production for each sector.
3	Dependence on industrial roundwood [index]	Less is better	National imports of industrial roundwood/ Apparent consumption of industrial roundwood
4	Unitary average wage	More is better	Average personnel costs per employee weighted by per capita income of each country
5	Gross value added per employee [1000 € /employee]	More is better	Gross value added/Number of employees
6	Intensity in labour force [index]	Less is better	Labour costs with respect to value of production
7	Investment rate	More is better	Total investment in the sector/Gross value added of the sector
8	Acquisition of built-in technology [1000 €/firm]	More is better	Gross investment in machinery and equipment/ Number of firms.
9	Innovative enterprises [index]	More is better	Number of innovative enterprises respect to the total number of enterprises for each sector
10	Effects of the innovation [%]	More is better	Turnover of the innovative enterprises respect to the total turnover for each sector
11	Patent applications	More is better	Patent applications to the EPO (European Patent Office) at sector level during the year 1993
12	External competitiveness	More is better	Revealed Comparative Advantage (Balassa Index). Competitive advantage in the international markets of the forest based products respect the rest of the commodities
13	Total waste [t/€]	Less is better	Total waste generated/Gross value added for each sector
14	Environmental protection expenditure [1000 €/employee]	More is better	Current expenditure in environmental protection/ Number of employees

Sources: European statistics (Eurostat) by theme: Industry, trade and services, Economy and finance, 4th Community Innovation Survey, Patent Statistics, Waste Statistics Regulation, Environmental Accounts. UNECE: Timber Committee Forest Products Statistics. UN Comtrade Database. Statistics Sweden. Czech Statistical Office. Statistik Austria

Table 2. Normalized indicator values for each country and each indicator. In bold, the ideal values, and in italics, the anti-ideal values.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Austria	0.258	0.597	0.404	0.834	0.872	0.345	0.169	0.894	**1.000**	0.604	0.082	0.198	0.843	0.905
Cyprus	0.118	0.933	0.842	0.345	0.252	*0.000*	0.271	0.022	0.630	0.598	*0.000*	0.024	0.952	0.120
Czech Republic	0.085	0.531	*0.000*	0.088	0.174	0.831	0.171	0.031	0.415	0.512	0.005	0.061	0.693	*0.000*
Estonia	0.056	0.577	0.608	0.141	0.091	0.590	0.739	0.005	0.826	*0.000*	*0.000*	0.049	*0.000*	0.186
Finland	**1.000**	0.643	0.477	**1.000**	**1.000**	0.581	0.011	**1.000**	0.652	**1.000**	0.068	**1.000**	0.618	**1.000**
France	0.098	0.735	0.034	0.704	0.505	0.223	0.047	0.158	0.487	0.676	0.341	0.070	0.833	0.617
Germany	0.100	0.638	0.459	0.822	0.604	0.129	0.139	0.510	0.964	0.856	**1.000**	0.073	0.965	0.969
Hungary	0.054	**1.000**	**1.000**	0.128	0.082	0.420	0.343	0.034	0.252	0.631	0.004	0.029	0.766	0.117
Italy	0.099	0.702	0.545	0.559	0.567	0.558	0.014	0.038	0.432	0.544	0.258	0.055	0.893	0.082
Latvia	0.003	0.783	0.902	0.054	0.032	0.654	0.895	0.021	*0.000*	0.128	*0.000*	0.049	**1.000**	0.021
Lithuania	*0.000*	0.480	0.397	0.093	0.060	0.657	0.335	0.003	0.300	0.553	0.001	0.011	0.807	0.066
Portugal	0.216	0.373	0.064	0.556	0.490	0.677	0.286	0.170	0.514	0.811	0.002	0.188	0.225	0.569
Romania	0.014	0.097	0.584	*0.000*	*0.000*	0.879	0.567	*0.000*	0.265	0.445	0.001	*0.000*	0.223	0.044
Slovakia	0.179	*0.000*	0.485	0.153	0.162	**1.000**	**1.000**	0.540	0.181	0.745	*0.000*	0.131	0.439	0.352
Spain	0.143	0.776	0.596	0.645	0.552	0.447	0.122	0.100	0.512	0.491	0.056	0.072	0.865	0.426
Sweden	0.549	0.451	0.014	0.714	0.919	0.446	0.110	0.572	0.911	0.887	0.108	0.460	0.599	0.877
United Kingdom	0.102	0.796	0.629	0.738	0.557	0.247	*0.000*	0.094	0.436	0.518	0.248	0.030	0.761	0.580

the indicators were obtained, the following step consisted of their normalization (see expression (1)). Table 2 shows the values of each indicator, now normalized, for each country selected. It should be noted that the ideal values for each indicator are in bold-face and the anti-ideal values in italics.

The following step is related to the obtaining of the weights which will be incorporated into the compromise programming models introduced above. The preferential weights have been obtained by means of a survey sent to 104 experts from 22 different countries. The experts have been selected for their publications, and their links to firms or organizations related to wood-based industries. In short, the experts had to compare, following a "pairwise" comparison format, the different indicators used in this model, employing the scale defined by Saaty in his AHP model (Saaty 1980). Twenty consistent responses were obtained, but some experts' judgements have not been computed for exceeding the consistency threshold required by the AHP procedure. In short, some experts have considerably departed from the transitive property when they respond to

Table 3. Preferential Weights obtained for each indicator.

Indicators		Weights
1	Gross value added [%]	0.105
2	Energetic efficiency [106 €]	0.113
3	Dependence on industrial roundwood [index]	0.057
4	Unitary average wage	0.045
5	Gross value added per employee [1000 €/employee]	0.093
6	Intensity in labour force [index]	0.049
7	Investment rate	0.064
8	Acquisition of built-in technology [1000 €/firm]	0.043
9	Innovative enterprises [index]	0.069
10	Effects of the innovation [%]	0.069
11	Patent applications	0.046
12	External competitiveness	0.102
13	Total waste [t/€]	0.065
14	Environmental protection expenditure [1000 €/employee]	0.079

the survey making paired comparisons. Although the number of surveys received could appear to be meagre, this is a habitual figure in this type of study (Caballero et al. 2008). On the other hand, in works tackling similar problems the opinion of experts is replaced by some weights conferred arbitrarily by the authors themselves, accompanied by a sensitivity analysis (Ruiz et al. 2011). From these answers the individual priorities of each expert were elicited. To obtain the aggregation of these preferences, it was opted, in accordance with previous studies (Forman and Peniwati 1998), to calculate their geometric mean for each indicator, so that their total sum was equal to one. The preferential weights obtained in this way are shown in Table 3.

5 Results

Table 4 shows the final ranking of the 17 countries, according to the different values of control parameter λ, when model shown in Eq. (5) has been applied.

It can be seen how Finland is the country with the most sustainable paper industry, unless we lean towards the most balanced solution ($\lambda=0$), in which case Sweden would be that country. In other words, except for that last solution, for the rest of the values associated with the control parameter λ the solutions are very alike, with the following four countries with the most sustainable paper industry: Finland, Sweden, Austria and Germany and the two countries with the least sustainable industry: Lithuania and Romania remaining invariable.

As was observed when explaining the methodology employed, the solution shown in Table 4 integrates the preferential weights of a set of experts shown in Table 3. The first question that we could ask ourselves is if the solutions are robust ones in the presence of changes in the preferential weights. The answer is incorporated into Table 5, where the problem has been solved by attaching the some preferential weight to each indicator.

It can be verified how, the same as in Table 4, the solutions are very similar to each other for the values of the control parameter λ higher than 0.1. In fact, in all these solutions shown in Table 5, the most sustainable country is Finland, followed by Germany, Austria and Sweden. Conversely, the least sustainable countries are the Czech Republic and Romania. On the other hand, and related to the most balanced solution ($\lambda=0$), the same type

Table 4. Results obtained for the different values of the parameter λ and preferential weights given by experts.

Rank	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	1
1	Sweden	Finland	Finland	Finland	Finland	Finland	Finland	Finland	Finland
2	Finland	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden
3	Austria	Austria	Austria	Austria	Austria	Austria	Austria	Austria	Austria
4	Portugal	Germany	Germany	Germany	Germany	Germany	Germany	Germany	Germany
5	Germany	Portugal	Portugal	Spain	Spain	Spain	Spain	Spain	Spain
6	Spain	Spain	Spain	Portugal	UK	UK	UK	UK	UK
7	France	France	France	UK	Portugal	France	France	France	France
8	Czech Rep.	UK	UK	France	France	Portugal	Portugal	Portugal	Portugal
9	Italy	Italy	Italy	Italy	Italy	Italy	Italy	Cyprus	Cyprus
10	UK	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Italy	Italy
11	Estonia	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary
12	Hungary	Estonia	Estonia	Slovak Rep.	Slovak Rep.	Slovak Rep.	Slovak Rep.	Slovak Rep.	Slovak Rep.
13	Cyprus	Czech Rep.	Slovak Rep.	Estonia	Latvia	Latvia	Latvia	Latvia	Latvia
14	Romania	Latvia	Latvia	Latvia	Estonia	Estonia	Estonia	Estonia	Estonia
15	Latvia	Slovak Rep.	Czech Rep.	Czech Rep.	Czech Rep.	Czech Rep.	Czech Rep.	Czech Rep.	Czech Rep.
16	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania
17	Slovak Rep.	Romania	Romania	Romania	Romania	Romania	Romania	Romania	Romania

Table 5. Results obtained for different values of the parameter λ, when the same weights are considered for the indicators selected.

Rank	0	0.1	0.5	1
1	Austria	Finland	Finland	Finland
2	Germany	Germany	Germany	Germany
3	Spain	Austria	Austria	Austria
4	France	Sweden	Sweden	Sweden
5	Sweden	Spain	Spain	Spain
6	Italy	France	UK	UK
7	Finland	UK	France	France
8	Hungary	Italy	Slovak Rep.	Slovak Rep.
9	Portugal	Slovak Rep.	Italy	Italy
10	Cyprus	Portugal	Portugal	Portugal
11	Latvia	Cyprus	Cyprus	Cyprus
12	Lithuania	Hungary	Hungary	Hungary
13	Romania	Latvia	Latvia	Latvia
14	Slovak Rep.	Estonia	Estonia	Estonia
15	UK	Lithuania	Lithuania	Lithuania
16	Czech Rep.	Czech Rep.	Czech Rep.	Czech Rep.
17	Estonia	Romania	Romania	Romania

of "ranking" is obtained when different preferential weights were integrated. However this solution ($\lambda=0$) differs considerably to the solution obtained when different preferential weights are considered. In fact, it can be observed how, in this case, the country with the most sustainable paper industry was Austria, followed by Germany, Spain and France.

6 Discussion and Conclusions

This work has presented a methodology by which the sustainability of the paper industry in Europe has been evaluated, using compromise programming for this purpose. The models employed permit the aggregation of a set of indicators of different types, as well as assigning different preferential weights to each of them. Also, different solutions have been obtained, according to the compromise between the most efficient solutions ($\lambda=1$) and the most balanced ones ($\lambda=0$). And what perhaps is the most important issue, all the solutions provided here have a clear preferential interpretation.

The results show how, with the exception of the case in which the solution is most balanced, Finland is the country with the most sustainable paper industry, followed by Sweden, Austria and Germany. At this point, one could compare this ranking with the structure of the European paper industry. In Table 6, data (production and number of employees) belonging to the 17 countries analysed in this paper are attached. Thus, some of the countries where production is higher (both in tons and in euros) are occupied by former top ranking. However, it appears that not always are countries with a high production or employing more workers are the most sustainable ones, as evidenced by the cases of Italy and the UK demonstrate. In addition, some studies could explain the results obtained in this paper. Thus, Kärnä et al. (2003) through a comparison of wood-based industries between different European countries, suggest that the Finnish firms are "greener" than those of other countries. Also, in Mikkilä et al. (2005) a survey was made of stakeholders in 4 countries, including Finland, in relation to aspects associated with the corporate social performance in the paper industry, showing how there is a greater environment awareness in Finland than in other countries. Finally, although this work does not aim to describe all the possible reasons for this ranking, people interested could developed statistical or econometric analyses in order to find some variables which explain the ranking of the countries analysed. Thus, the dependent variables could be the numerical values obtained by applying the above CP models, and a new set of independent variables (different to the indicators chosen in this paper) could be selected as explanatory variables.

A possible weakness in this paper might be the selection of the indicators, conditioned by the data existing at the level tackled in this study. For example, other additional indicators of an environmental nature could be included, and issues regarding the interdependence of the different wood product markets (Kallio 2001) have not been addressed with this battery of indicators. Thus, a possible extension of this research would consist of adapting the analysis at a more disaggregated level, for instance at a managerial one, or analysing in more detail certain industrial sub-groups. Besides, if the proposed indicators have been

Table 6. Main figures of the European paper industry regarding the countries analysed in this research (year 2004).

	Employees (1000 persons)	Production (1000 €)	Production (1000 t)
Austria	17.8	4846.5	4852.0
Cyprus	0.9	63.0	0.0
Czech Republic	19.3	1675.1	934.0
Estonia	1.7	93.1	65.8
Finland	37.1	13678.9	14036.0
France	84.4	17765.6	10255.0
Germany	147.6	30211.0	20391.0
Hungary	18.7	944.3	579.0
Italy	75.8	17697.5	9667.0
Latvia	1.7	55.6	38.0
Lithuania	2.1	92.7	99.0
Portugal	12.8	2293.2	1664.0
Romania	17.1	494.9	454.0
Slovakia	7.9	814.3	798.0
Spain	54.4	10833.5	5526.0
Sweden	40.2	12447.6	11589.0
United Kingdom	81.2	16741.6	6240.0
Total	620.4	130748.4	87187.8
EU	733.7	147000.0	96238.9

Source: EUROSTAT

defined at an entrepreneurial level, environmental aspects like the "triple bottom", eco-efficiency, or the installation of certain environmental management systems could be addressed with a different battery of indicators. However, in that case, the methodology used to aggregate the indicators would be the same.

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References

André, F.J. & Romero, C. 2008. Computing compromise solutions: on the connection between compromise programming and composite programming. Applied Mathematics and Computation 195(1): 1–10.

Babaie-Kafaky, S., Mataji, A. & Sani, N.A. 2009. Ecological capability assessment for multiple-use in forest areas using GIS- based multiple criteria decision making approach. American Journal of Environmental Sciences 5(6): 714–721.

Balana, B., Mathijs, E. & Muys, B. 2010. Assessing the sustainability of forest management: an application of multi-criteria decision analysis to community forests in northern Ethiopia. Journal of Environmental Management 91(6): 1294–1304.

Blancas, F.J., Caballero, R., González, M., Lozano-Oyola, M. & Pérez, F. 2010. Goal programming synthetic indicators: An application for sustainable tourism in Andalusian coastal counties. Ecological Economics 69(11): 2158–2172.

Bousson, E. 2001. Development of a multicriteria decision support system adapted to multiple-use forest management: application to forest management at the management unit level in Southern Belgium. In: Franc, A., Laroussinie, O. & Karjalainen, T. (eds.). Criteria and indicators for sustainable forest management at the forest management unit level. EFI Proceedings 38. p. 151–164.

Buongiorno, J., Zhu, S., Zhang, D. & Turner, J. 2003. The global forest products model. structure, estimation and applications. Academic Press, San Diego. 301 p.

Caballero, R., Gil, A. & Fernández-Santos, X. 2008. An experts survey on sustainability across twenty-seven extensive European systems of grassland management. Environmental Management 42(2): 190–199.

Carabelli, E., Bigsby, H., Cullen, R. & Peri, P.L. 2007. Measuring sustainable forest management in Tierra del Fuego, Argentina. Journal of Sustainable Forestry 24(1): 85–108

Diaz-Balteiro, L. & Romero, C. 2004a. Sustainability of forest management plans: a discrete goal programming approach. Journal of Environmental Management 71 (4): 349–357.

— & Romero, C. 2004b. In search of a natural systems sustainability index. Ecological Economics 49(3): 401–405.

— & Romero, C. 2008. Making forestry decisions with multiple criteria: a review and an assessment. Forest Ecology and Management 255(8–9): 3222–3241.

Ducey, M.J. & Larson, B.C. 1999. A fuzzy set approach to the problem of sustainability. Forest Ecology and Management 115: 29–40.

Forman, E. & Peniwati, K. 1998. Aggregating individual judgments and prorities with the Analytic Hierarchy Process. European Journal of Operational Research 108(1): 165–169.

Gómez-Limón, J.A. & Sánchez-Fernández, G. 2010. Empirical evaluation of agricultural sustainability using composite indicators. Ecological Economics 69(5): 1062–1075.

Hart, S., Arnold, M. & Day, R. 2000. The business of sustainable forestry: meshing operations with strategic purpose. Interfaces 30(3): 234–254.

Huth, A., Drechsler, M. & Köhler, P. 2005. Using multicriteria decision analysis and a forest growth model to assess impacts of tree harvesting in Dipterocarp lowland rain forests. Forest Ecology and Management 207(1–2): 215–232.

Johnson, A. & Walck, D. 2004. Certified success: integrating sustainability into corporate management systems. Journal of Forestry 102(5): 32–39.

Kallio, A.M.I. 2001. Interdependence of the sawlog, pulpwood and sawmill chip markets: an oligopsony model with an application to Finland. Silva Fennica 35(2): 229–243.

Kangas, J., Alho, J.M., Kolehmainen, O. & Mononen A. 1998. Analyzing consistency of experts' judgements-case of assessing forest biodiversity. Forest Science 44(4): 610–617

Kärnä, J., Hansen, E. & Juslin, H. 2003. Environmental activity and forest certification in marketing of forest products – a case study in Europe. Silva Fennica 37(2): 253–267.

Korhonen, J., Wihersaari, M. & Savolainen, I. 2001. Industrial ecosystem in the Finnish forest industry: using the material and energy flow model of a forest ecosystem in a forest industry system. Ecological Economics 39(1): 145–161.

Lähtinen, K., Haara, A., Leskinen, P. & Toppinen, A. 2008. Assessing the relative importance of tangible and intangible resources: empirical results from the forest industry. Forest Science 54(6): 617–616.

Maness, T. & Farrell R. 2004. A multi-objective scenario evaluation model for sustainable forest management using criteria and indicators. Canadian Journal of Forest Research 34(10): 2004–2017.

Mendoza, G.A. & Dalton, W.J. 2005. Multi-stakeholder assessment of forest sustainability: multi-criteria analysis and the case of the Ontario forest assessment system. Forestry Chronicle 81(2): 222–228.

— & Prabhu, R. 2000a. Development of a methodology for selecting criteria and indicators of sustainable forest management: a case study on participatory assessment. Environmental Management 26(6): 659–673.

— & Prabhu, R. 2000b. Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: a case study. Forest Ecology and Management 131(1–3): 107–126.

— & Prabhu, R. 2003. Qualitative multi-criteria approaches to assessing indicators of sustainable forest resource management. Forest Ecology and Management 174(1–3): 329–343.

— , Hartanto, H., Prabhu, R. & Villanueva, T. 2002. Multicriteria and critical threshold value analyses in assessing sustainable forestry: Model development and application. Journal of Sustainable Forestry 15(2): 25–62.

Mikkilä, M., Kolehmainen, O. & Pukkala T. 2005. Multi-attribute assessment of acceptability of operations in the pulp and paper industries. Forest Policy and Economics 7(2): 227–243.

Nyrud, A.Q. & Baardsen, S. 2003. Production efficiency and productivity growth in Norwegian sawmilling. Forest Science 49(1): 89–97

Ojala, J., Lamberg, J.-A., Ahola, A. & Melander, A. 2006. The ephemera of success: strategy, structure and performance in the forestry industries. In: Lamberg, J.-A., Näsi, J., Ojala, J. & Sajasalo, P. (eds.). The evolution of competitive strategies in global forestry industries. Springer, Dordrecht, The Netherlands. p. 257–286.

Östlund, S. & Roome, N.J. 1998. Sustainable forestry management as a model for sustainable industry: A case study of the Swedish approach. In: Roome, N.J. (ed.). Sustainability strategies for industry. The future of corporate practice. Island Press, Washington, DC. p. 203–221.

Paech, N. 2005. Directional certainty in sustainability-oriented innovation management. In: Lehmann-Waffenschmidt, M. (ed.). Innovations towards sustainability. Conditions and consequences. Physica-Verlag, Heidelberg, Germany. p. 121–139.

Raison, R.J., Brown A. & Flinn, D. 2001. Criteria and indicators for sustainable forest management. CABI Publishing, Wallingford, UK. 427 p.

Romero, C. 1991. Handbook of critical issues in goal programming. Pergamon Press, Oxford. 124 p.

Ruiz, F., Cabello, J.M. & Luque, M. 2011. An application of reference point techniques to the calculation of synthetic sustainability indicators. Journal of the Operational Research Society 62(1): 189–197.

Saaty, T. 1980. The Analytic Hierarchy Process: planning, priority setting, and resource allocation. McGraw-Hill, New York. 287 p.

Singh, R.K., Murty, H.R., Gupta, S.K. & Dikshit A.K. 2007. Development of composite sustainability performance index for steel industry. Ecological Indicators 7(3): 565–588.

Stendahl, M. 2009. Management of product development projects in the wood industry. Scandinavian Journal of Forest Research 24(5): 434–447.

Store, R. 2009. Sustainable locating of different forest uses. Land Use Policy 26(3): 610–618.

Vacik, H., Wolfslehner, B., Seidl, R. & Lexer, M.J. 2007. Integrating the DPSIR approach and the Analytic Network Process for the assessment of forest management strategies. In: Reynolds, K.M., Thomson, A.J., Köhl, M., Shannon, M.A., Ray, D. & Rennolls, K. (eds.). Sustainable forestry: from monitoring and modelling to knowledge management and policy science. CABI, Wallingford, UK. p. 393–411.

Voces, R., Diaz-Balteiro, L. & Romero, C. 2010. In search of a European paper industry ranking in terms of sustainability by using binary goal programming. Lecture Notes in Economics and Mathematical Systems 638: 141–149.

Wolfslehner, B. & Vacik, H. 2008. Evaluating sustainable forest management strategies with the Analytic Network Process in a Pressure-State-Response framework. Journal of Environmental Management 88(1): 1–10.

— & Vacik, H. 2011. Mapping indicator models: from intuitive problem structuring to quantified decision-making in sustainable forest management. Ecological Indicators 11(2): 274–283.

— , Vacik, H. & Lexer, M.J. 2005. Application of the analytic network process in multi-criteria analysis of sustainable forest management. Forest Ecology and Management 207(1–2), 157–170.

Yu, P.L.1973. A class of solutions for group decision problems. Management Science 19(8): 936–946.

Zeleny, M. 1974. A concept of compromise solutions and the method of the displaced ideal. Computers & Operations Research 1(3–4): 479–496.

Zhou, P., Ang, B.W. & Poh, K.L. 2007. A mathematical programming approach to constructing composite indicators. Ecological Economics 62(2): 291–297.

Total of 48 references