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Assessment of port sustainability through synthetic indexes. Application to the Spanish case

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ABSTRACT

In general, Synthetic Indexes of sustainability have been applied to specific countries and regions. With some variations, the ones considered simple, such as the case of the Ecological Footprint (EF), have been applied to port areas. The same has not happened with those of a multidimensional nature (Global Synthetics) that still have a minimal and partial presence in the analysis of port sustainability.
Understanding that this type of index represents an interesting and novel avenue of research applied to port systems, this contribution analyses and ranks a sample of 16 Spanish Port Authorities that group 23 ports of general interest using a Global Synthetic Index of Sustainability (developed using the four dimensions of sustainable development: economic, institutional, environmental and social).

1. Introduction and objectives

Synthetic Indexes are traditionally used in economics to obtain aggregate information from a set of variables that are grouped into different levels of hierarchy. Sustainable development is a complex and multidimensional issue, so its evaluation requires the specific development of this kind of index, obtained through aggregations of individual variables (Bluszcz, 2016). In issues of sustainability, the most important applications in this area have been carried out in two categories: simple and global. The most important ones and the main contributions for each of them can be summarised as outlined in Table 1.

These indices were initially applied to countries, and then to areas or regions. Nevertheless, as regards simple synthetics (EF), very specific experiments for their use in port areas have already been conducted (Carrera Gómez et al. 2006; Coto Millán et al. 2010). However, to date no Global Synthetic Indexes have been proposed to measure port sustainability, although there have been references to certain partial aspects as in the case of economic and environmental dimensions (González Laxe et al. 2016).

Indeed, this path has been recently opened by Sislian, Jaegler and Carou (2016) who, following a complete and thorough review of the literature on port sustainability, recommend addressing it globally and from a three-dimensional perspective: economic, social and environmental. For these authors, this represents the new challenge in future research in this area.

Elsewhere, those three dimensions of sustainable development have been considered as basic, in the sense of providing them with a comprehensive approach to define sustainability from a multidimensional perspective. However, the latest recommendations on the subject advocate the inclusion of a fourth aspect: the institutional dimension, understood as the definition of transparent and independent forms of governance with objective criteria, so that the institutions themselves formulate policies to ensure the development of the other three dimensions. This dimension is therefore conceived as the one that propitiates the development and equilibrium of the others (Fernández Francos, Martín Palmero and Serrano Hidalgo, 2013).

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Table 1
Main synthetic indexes of sustainability.
Source: own elaboration, based on the classification of synthetic indicators proposed in Martín Palmero (2004).

		References	Characteristics
Simple	Ecological footprint (EF)	Wackernagel and Rees (1996)	It measures the area necessary to produce resources and assimilate the waste of a given population
Global	Environmental performance index (EPI)	World Economic Forum (2006-2016)	It initially develops a five-dimensional synthetic index for 146 countries (178 in 2014)
	Sustainable society index (SSI)	Van der Kerk and Manuel (2014)	This is based on 21 sustainability and quality of life indicators grouped into 5 categories for 150 countries.
	Synthetic indicator of sustainable development (SISD)	Bluszcz (2015)	It proposes a synthetic index for the 28 EU countries distributed in 3 dimensions (human, economic and environmental)

For its contribution within that line of proposed research, a Global Synthetic Index[1] (SI) is formulated and designed to measure Port Sustainability that is structured in a pyramid shape. The Synthetic Index comprises the four components or dimensions already defined (economic, institutional, environmental and social) divided into various indicators. These come from the calculation of a specific number of sub-indicators, each comprising a series of variables.[2] The variables considered essential to generate the Synthetic Index will be defined from the information and data contained in the Reports on Sustainability of the Spanish Port System.

2. Selection of variables and determination of the sample

Spanish Law 33/2010[3] on State Ports and the Merchant Marine establishes as one of the instruments for planning the port system of general interest is the need to introduce an annual plan in line with the Government's economic policy. This plan must be accompanied by a Sustainability Report developed in accordance with the methodology approved by *Puertos del Estado* (State Ports).[4]

The selection process of variables starts with the data contained in the Sustainability Reports of the 46 Spanish ports of general interest integrated into 28 Port Authorities (PAs), in this case for 2012 (González Laxe et al. 2016). Given that the variables to be considered should be measured in quantitative and relative terms, the maximum that can be selected (obtained either directly from the Reports or from derivative calculations) amounts to 56. Therefore, theoretically the total variables to be taken into consideration for the research would be 1568.

However, a thorough analysis of the information available in the Reports of each PA and its adaptation to the methodological specifications of State Ports on occasions reveals cases with shortfalls and a lack of information. Particularly, four ports do not reach 60% of their variables covered acceptably, while eight fail to reach 80%. Therefore, if the 28 Port Authorities are taken into consideration in the analysis, it is likely that the results of the research would prove inconsistent. To avoid this problem, through a continuous process of selection, an adequate sample comprising 16 Port Authorities has been considered as an appropriate sample (managing 23 ports) with an overall variables completion rate of 88.95%.[5] The distribution by dimensions is shown in Table 2.

Given that the Synthetic Index is constructed in a pyramidal shape, it is necessary to define how each of the 56 variables are grouped for each PA within the respective sub-indicators and these, in turn, into indicators, which make up each of the dimensions. This enables the integral and multidimensional perspective of sustainability to be collected. The groupings are shown in Table 3 and the breakdown of each of the components is included in the respective appendices.

3. Calculation methodology

Having determined the sample and selected the variables as noted in the previous section, the methodology based on which all the operational calculation of the Synthetic Index on Sustainability and its components consists of the following stages:

1. The first stage is carried out by forming the composite database with the different values observed and obtained from each of the 56 variables for each of the 16 Spanish PAs that make up the sample.
2. Then the values of the percentiles 97.5 and 2.5 are obtained with which to replace the maximum and minimum values of each of the variable values. This enables any excessively dispersed values to be corrected. The subsequent performance of the respective normality tests will serve to determine whether it should be carried out with more adjusted percentiles.
3. In third place, regarding the resulting distribution, the *Z*-score is calculated for each variable, in other words the typified values, so that these are comparable. The calculation can be obtained in two different ways:

$$Zs_i = \frac{Xi - \overline{X}}{\sigma x},$$

if the sense of sustainability is direct,[6] or

$$Zs_i = \frac{\overline{X} - Xi}{\sigma x},$$

if it is the other way round. In both cases:

Zs_i = Value of the typified variable.

$\overline{X}$ = Distribution average.

Xi = Value reached by the variable.

σx = Typical deviation of distribution.

4. Once every calculation of the 56 variables considered for the 16 PAs has been generated, it is necessary to continue with the subsequent process of identifying indicators, whose values are obtained by

[1] González Laxe and Martín Palmero (2004) developed a similar methodology to study and classify EU countries in accordance with a Synthetic Index on Sustainability, and González Laxe, Martín Palmero and Fernández Francos (2004), for the Spanish regions.

[2] The design of the variable selection methodology for calculation of a Synthetic Index of Sustainability of the Spanish Port System and the corresponding application were developed through a Research Agreement between the organisation *Puertos del Estado* and the University Institute of Maritime Studies of the UDC in 2013 and 2014.

[3] Consolidated text approved through Royal Legislative Decree 2/2011.

[4] The methodology considers 111 indicators or obligatory variables of a descriptive, categorical or quantitative nature. A full development of the same can be consulted at Barcelona Port (2012).

[5] To achieve a percentage of 93.75% it would be necessary to restrict the sample to 6 ports, which would extremely limit the analysis. The 8 port authorities excluded from the final sample through insufficient information in their Reports are: A Coruña, Alicante, Almería, Balearic Islands, Bay of Cádiz, Ceuta, Ferrol, Marín, Pasajes, Tenerife, Seville and Tarragona

[6] The direct sense of sustainable development is understood when a higher value of the variable means a higher level of sustainability. When a lower value of the variable is indicative of greater sustainability, an indirect sense shall be understood.

Table 2
Variables valid for a sample of 16 port authorities.
Source: own elaboration.

Dimension	Variables		%
	Theoretical	Valid	
Economic	224	211	94.20
Institutional	160	122	76.25
Environmental	304	260	85.53
Social	208	204	98.08
Total	896	797	88.95

calculating the mean of the *Z*-scores of the variables, classified and weighted in accordance with the sub-indicators that make up each of those.
5. The next and final stage of this initial process involves:

a) Obtaining the standardised values of each SI component or dimension (economic, institutional, environmental and social) through the weighted average of Z-scores calculated for the indicators. The results are included in Table 4.
b) Verifying that the results obtained are meaningful and consistent, for which it should be ascertained whether those standardised values for each of the four dimensions are representative of a normal distribution. The Kolmogorov - Smirnov test is therefore carried out using the SPSS statistical programme. The results - which are included in Table 5 - determine very high significance levels for each dimension, above 0.05 which is set as the lower limit for the normality test. This enables the null hypothesis that the variables follow a normal distribution to be checked.
c) Having checked the normality of distributions, the standardised values obtained as described previously are then transformed, so they can be compared and understood. For this, the *Z*-score of each dimension becomes the standard normal percentile, with a theoretical value of between 0 and 100.
d) Lastly, weighting the average of the percentiles obtained for each one of the dimensions or components of the Index to calculate the value of the Synthetic Index. The results and order of these last two stages are included in Table 6.

4. Results

By analysing the data derived from the composition and distribution of the Synthetic Index in their respective dimensions, the following would be observed:

a) The value reached in the SI for each of the 16 PAs that make up the sample under study: logically, the values close to zero indicate a very low level of sustainable development and those close to 100 a very high one, always regarding the remaining PAs and within the set considered.
b) Values of the components of the mentioned SI classified within their economic, institutional, environmental and social dimensions: the same as for the Synthetic Index, those close to 100 will determine a broad level in each dimension and those close to 0 will be indicative of unsustainability.

To make the analysis more meaningful and to enable the characteristics of each PA to be appreciated visually and synthetically, their four components are represented by a radial or diamond graph constructed so that each vertex represents the four dimensions of sustainability. The radius scale stands at 0 to 100, whereby the positions closest to the centre are indicative of low values of the components while those close to the vertexes represent the highest. The construction of the graph is deliberately done like this because:

- It reflects the level of the dimensions of sustainable development in each of the PAs dealt with.
- It determines the balance between them, which is essential for sustainability; in fact, by filling the area between the values of the components, a surface area in proportion with the SI is obtained. Based on this feature, the higher levels of sustainable development would be achieved in two ways: quantitatively, when the filled-in part is greater (higher values of components), and qualitatively, when the values of these components are similar or, put another way, when the borders of the plot area tend to be parallel with the edges of the graph. This circumstance explains the balanced position between dimensions, determining that the four complement each other, replace and are used efficiently irrespective of their level.

Fig. 1 shows the radial charts of the 16 PAs, constructed in accordance with the values obtained for each dimension.

Table 3
Composition of the sample of variables based on the number of dimensions, indicators, and sub-indicators.
Source: own elaboration.

Dimension	Indicators	Sub-indicators	Variables
Economic	2	5	14
Institutional	2	5	10
Environmental	3	8	19
Social	4	6	13
Total	11	24	56

Table 4
Values by dimensions.

		Economic	Institutional	Environmental	Social
1	Avilés	−0.0215714	−0.4019130	−0.3407579	−0.2423231
2	Barcelona	0.5766857	0.5930413	−0.0087526	0.1342923
3	Bay of Algeciras	0.5979428	−0.0761846	0.0010736	0.1141538
4	Bilbao	0.0439142	0.5295990	0.0735684	0.3456231
5	Cartagena	0.9116857	−0.5425761	−0.1301053	0.1294615
6	Castellón	−0.0944429	0.0473826	−0.2846579	0.5016846
7	Gijon	0.0097142	0.5795329	−0.0597947	−0.0966308
8	Huelva	0.1440142	0.0185999	0.0809526	−0.6723077
9	Las Palmas	−0.0206714	−0.0224681	0.4205210	−0.0902692
10	Malaga	−0.5264000	−0.1046799	0.3907684	−0.555400
11	Melilla	−0.3888143	−0.1122301	−0.0021947	0.1066692
12	Motril	−0.7079714	−0.6237201	−0.1771053	−0.1350692
13	Santander	−0.3935000	−0.1158507	−0.4961474	−0.2074385
14	Valencia	0.2569428	0.3748668	0.1493789	0.0584462
15	Vigo	−0.0757571	−0.1854996	0.2498526	−0.0243308
16	Vilagarcía	−0.2126571	0.6436477	−0.1309579	0.469300

Source: own elaboration.

Table 5
Kolmogorov-Smirnov test.
Source: own elaboration with the SPSS statistical software.

		Economic	Institutional	Environmental	Social
N		16	16	16	16
Normal parameters[a, b]	Average	0.0062	0.0376	−0.1650	−0.0103
	Typical deviation	0.42853	0.40212	0.24957	0.32154
Most extreme differences	Absolute	0.152	0.175	0.098	0.139
	Positive	0.152	0.178	0.098	0.139
	Negative	−0.096	−0.139	−0.075	−0.110
Z de Kolmogorov-Smirnov		0.610	0.711	0.392	0.556
Asympt. signif. (bilateral)		0.851	0.693	0.998	0.917

[a] The contrast distribution is the Normal one.
[b] Calculated from data.

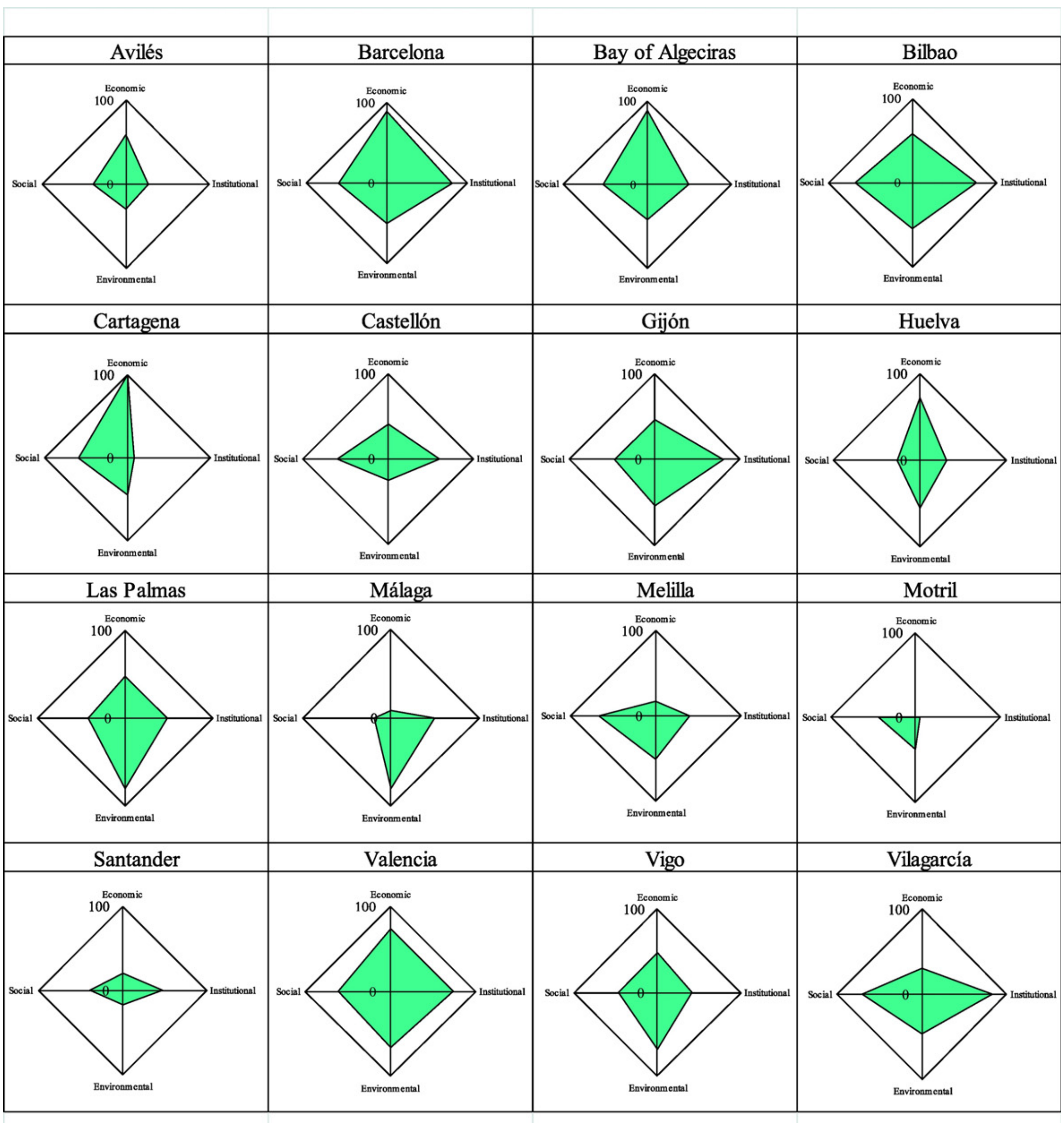
Table 6
Results by port authorities, dimensions and synthetic index (SI).
Source: own elaboration.

	Economic	Institutional	Environmental	Social	SI
Avilés	59.03	26.66	29.42	38.92	38.53
Barcelona	89.50	81.28	49.81	59.95	67.71
Bay of Algeciras	88.51	49.32	42.06	52.80	57.46
Bilbao	58.09	75.96	54.38	67.69	62.25
Cartagena	100.00	7.94	44.17	58.95	55.09
Castellón	40.93	59.94	24.90	59.98	43.31
Gijón	46.60	80.00	53.99	47.15	55.20
Huelva	72.31	30.64	54.71	26.12	48.18
Las Palmas	47.60	48.00	80.32	42.00	57.47
Málaga	8.51	49.28	79.61	18.94	42.34
Melilla	17.10	39.94	50.83	66.64	44.12
Motril	0.00	5.32	37.51	43.03	23.66
Santander	20.00	46.64	17.18	38.95	28.20
Valencia	73.30	73.32	65.96	61.51	68.08
Vigo	47.59	41.30	68.03	46.62	53.18
Vilagarcía	30.43	82.64	46.63	70.24	54.49

4.1. Overall results

Valencia PA ranks first (68.08) in the value of the Synthetic Index, a result of being in the top positions in the four dimensions of sustainability, followed closely by Barcelona (67.71) and Bilbao (62.25). In addition to those with the highest ranking in the SI value, these three ports could also be considered to have the best balance between dimensions. Valencia and Bilbao are particularly prominent in this regard. At the opposite extreme, those of Santander (28.20) and Motril (23.66) occupy the last positions in the index, standing out as the least sustainable of the sample.

It is worth noting the importance of the results regarding the balance between dimensions: the PA of Valencia, besides being the most sustainable globally, has a great symmetry in the values of each aspect of sustainability. Bilbao also merits attention for this characteristic, and Barcelona (the second highest SI), however, achieves a more discreet value in the environmental dimension. On the opposite side, four PAs offer a great imbalance in one or more dimensions: Cartagena



Source: own elaboration.

Fig. 1. Diagrams of port sustainability.

(Institutional); Malaga (Economic and Social); Melilla (Economic) and Motril (Economic and Institutional).

4.2. By dimensions

Next, an analysis of the most significant results obtained by the Spanish PAs within each dimension is set out, in an attempt to explain these results through the values achieved by the Port Authorities in the intermediate calculations of indicators.

4.2.1. Economic

Cartagena achieves the maximum percentile value (100) in this aspect of sustainable development. The reason lies in the fact that it presents the best values in the Business and Services and Economic Structure Indicators. In second place is Barcelona (89.5), followed by Algeciras in third place (88.51). In the last places are the PAs of Melilla (17.1), Malaga (8.51), as well as Motril (0), a Port Authority that presents the lower values of the indicators that make up the economic dimension.

4.2.2. Institutional dimension

The first position in this dimension is taken by Vilagarcía (82.64). Barcelona (81.28) and Gijón (80.00) have virtually similar values. These three PAs have a particularity: they stand out considerably in the Institutional Capacity indicator and are ranked lower in the Protection of human and natural Capital. The last positions in the institutional dimension correspond to Avilés (26.66), Cartagena (7.94) and Motril (5.32), which have particularly low values in the two indicators that make up the institutional dimension.

4.2.3. Environmental dimension

The first position in the hierarchy is occupied by Las Palmas (80.32), because of the positive results of the indicators of Environmental management, Eco-efficiency and, to a lesser extent, Environmental quality. Second, but very close in the hierarchy, is Malaga (79.61), followed by Vigo (68.03). The last position in this dimension is taken by Santander (17.18).

4.2.4. Social dimension

In this dimension, Vilagarcía port ranks first (70.24) because of the positive values presented in the indicators of Human capital and Health. It is followed in the pecking order by Bilbao (67.69) and Melilla (66.64). The last positions are taken by Huelva (26.12) and Malaga (18.94).

5. Conclusions

Global Synthetic Indicators on Sustainability, covering the full scope of sustainable development (in its environmental, economic, institutional and social dimensions) are diagnostic tools that also offer a broad perspective, and can therefore be instruments for the Port Authorities to increase their chances of coping with and receiving traffic, enhance their attractiveness capabilities, and provide sufficient information to both users of the activity and stakeholders.

The new requirements for the implementation of measures to improve standards related to the environment, transparency in management and accurate and continuous information have encouraged the inclusion of standards and aspects related to the synthetic activity indicators into port policies.

In the port area of the European Union, both the ESPO and some countries have adopted decisions in this regard (the case of Spain is particularly relevant as the country's legislation includes the obligatory nature of drawing up and presenting a report every year on the ratios and progress in this area). In some cases, the most pressing concerns have been highlighted and, in other cases, the methodological criteria for defining indicators have been clarifies more accurately.

This research shows how the ports that move more goods at their facilities have higher Synthetic Indexes on Sustainability than the rest and a better balance in the four dimensions. This would mean that they pay more attention to a global and integrated management, because they should be very attentive to both the demands of users and permanently adapt themselves to new conditions of international inter-port competition and the demands of citizens. Thus, the PAs of Valencia, Algeciras, Barcelona and Bilbao (the four first Spanish ports in terms of total port traffic) are top of the ranking established by the Synthetic Port Sustainability Index.

Ports with very marked levels of specialisation because of the different traffic of goods or bulk loads reveal very different behaviours. The Port Authorities with a high percentage of bulk solids at their facilities - such as the cases of Gijón (where 89% of its total traffic responds to those bulk loads), Malaga (60%) or Santander (63%) - have been keen to show good ratios in the institutional and environmental dimensions. Thus, these two dimensions mark a widespread trend: the higher the environmental concerns of their facilities, the greater the efforts made to prevent and control the adverse effects on the environment. In parallel, these Port Authorities also focus more measures and greater attention on improving the institutional dimension approach. Probably the fact of concentrating traffic that is highly conditioned to the specific facilities (coal or bulk solids) places greater demands on those two dimensions.

Regarding ports with high level of specialisation of bulk liquid traffic - which is the case of Cartagena (79%), Huelva (79%), Motril (59%), Bilbao (56%) and Castellón (52%) - the results are more heterogeneous. However, at these PAs the dimensions with a better position are the economic and environmental ones: they are ports with a good financial situation and optimal trading figures that simultaneously act on environmental issues because of the need to control any negative effect on health of both the ecosystem and the urban environment itself. The presence of some facilities where there are risks (refineries or gas plants, for example) require such attention. The diagrams of these PAs are not as balanced as in the previous case, with certain ports showing an inclination towards the economic dimension (Cartagena and Huelva); and others towards the environmental dimension (Cartagena and Castellón).

Ports with higher levels of containerisation are characterised by a tendency to show a high level regarding the institutional dimension. The first five Spanish ports in terms of containers (Algeciras, Valencia, Barcelona, Bilbao and Las Palmas) are part of the first group of Port Authorities in this dimension. Moreover, the diagrams of their dimensions are more balanced.

Smaller ports in terms of total traffic (Avilés, Melilla, Motril, Vilagarcia) are those which show great heterogeneity. There is no constant, nor a common pattern among them: some stand out in the institutional dimension (Vilagarcia); others in the economic dimension (Avilés); others in the social dimension (Melilla); and finally, another in the environmental dimension (Motril).

The experience of this research suggests, in turn, new lines. On the one hand, the contribution of the Synthetic Port Sustainability Index could serve as a permanent assessment, allowing benchmarking between all European ports, once the methodology to be used has been homogenised. On the other hand, it serves to provide public administrations with a wake-up call, and a message from the public to those in charge of the ports and to the users of their facilities with a view to incorporating these Indexes into the commitments of business corporate social responsibility of the Port Authorities and the national port systems. Third, this contribution can also portend an improvement in all areas of management, as well as demands greater than those currently shown by some certification agencies that are not internationally comparable. Finally, its application allows the creation of port sustainability standards which, once defined, serve as objective functions of the various public policies to be developed in this area.

Appendix A. Description of the variables

Economic Dimension

Indicator	Subindicator	Description
Economic structure	Value generated and productivity	Turnover per employee
		EBIDTA per employee
	Economic and financial situation	Return on assets
		EBIDTA by tonnes
		Debt servicing
		Unused assets
		Operating costs/operating revenue
	Level and structure of investments	Public investment/Cash Flow
		Third-party investment/public investment
		Asset renewal rate
Business and servicing	Business	Occupancy rate/Net turnover
		Activity rate/Net turnover
	Services	Tonnes per square metre service area
		Tonnes per metre active dock

Institutional Dimension

Indicator	Subindicator	Description
Institutional Capacity	R&D + i activities, port-city interface and promotion	Investment and expenses in R&D + i
		Investment and expenses in improving port-city interface
		Trade promotion
	Social action	Investment and expenses in cultural initiatives, social schemes, foundations, etc.
	Infrastructure and services	% of land area for commercial use, licensed
		% of tonnes moved in licensed area over total freight traffic
		Use of railway
		Use of loading and unloading by Ro-Ro
Protection of human and natural capital	Risks for human capital	Economic resources used in protection and security
	Risks for natural capital	Economic resources used in environmental issues

Environmental Dimension

Indicator	Subindicator	Description
Environmental management	Economic Behaviour of the PA in environmental issues	Investments associated to the introduction of an environmental management system
		Costs associated to the introduction of an environmental management system
		Investments in environmental characterisation and monitoring
		Costs in environmental characterisation and monitoring
		Costs in terrestrial cleaning
		Costs in cleaning the water surface
	Environmental training	Percentage of workers with environmental training
Eco-efficiency	Efficiency in ground use	Percentage of the terrestrial service area occupied on asset facilities
	Energy consumption	Percentage of electricity consumption by the service zone surface area
		Percentage of fuel consumption by the service zone surface area
	Water consumption	Percentage of water consumption by the service zone surface area
Environmental quality	Quality of interior waters	Percentage of terrestrial surface area that has rainfall collection network

(*continued*)

Indicator	Subindicator	Description
		Percentage of service zone surface area that has rainfall collection network
	Wastewater treatment	Percentage of the terrestrial service zone that has a water treatment network (irrespective of where it discharges and the treatment received)
		Percentage of the terrestrial service zone that has a treatment network connected to the municipal collector or WWTP
		Percentage of surface area that discharges into septic tanks
	Recovery of waste	Percentage of SUW recovery
		Percentage of hazardous waste recovery
		Percentage of recovery of oils

Social Dimension

Indicator	Subindicator	Description
Social Capital	Employment	Temporary workers over all full-time workers
		Percentage of employees covered by collective bargaining agreement
Human Capital	Training	Percentage of workers within the agreement that follow training programmes.
		Percentage of workers outside the agreement that follow training programmes.
		Percentage of training hours for workers within the agreement.
		Percentage of training hours for workers outside the agreement.
Fairness	Gender equality	Percentage of woman regarding all workers
		Percentage of woman outside the agreement regarding all workers outside the agreement
	Labour structure	Personnel renewal rate
Health	Occupational accidents	Annual frequency of accidents index
		Annual severity of accidents index
		Annual absenteeism index
	Occupational health and safety	Training effort in prevention

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