WATER SUSTAINABILITY: A CASE STUDY USING SOCIAL AND ECONOMIC METABOLISM PERSPECTIVE

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ABSTRACT
The search for sustainability, which is understood as a situation that ensures the basic needs of the present while guaranteeing these exact needs for future generations, is present in each of the agendas of the highest authorities of the different countries around the world. In this same context, the study of efficiency in the use of aquatic resources and the interconnections between water use and socio-economic variables within a society will provide enormously beneficial information for studying the sustainability of this element. The main objective of this research is to know the principal uses of water and its interactions with socio-economic factors within the Spanish State. For this purpose, we use the MuSIASEM methodology, a technique capable of identifying and taking the economic, social, cultural, political, technical, and environmental dimensions in a precise analysis. Therefore, this method can study this element extensively, enriching the research through multivariate techniques, such as the HJ-Biplot. This study proves the effectiveness of the MuSIASEM methodology and the multivariate technique HJ-Biplot in the practical case of the Spanish State during 2018. We concluded that the complementation of both methods achieves an efficient and exhaustive study of the relationships and individual behaviour of the different social, economic, and water use-related variables. After that, these results can be used to study how to reduce the consumption of water resources in the Spanish State and achieve a fair and respectable consumption for both humanity and the planet.
Keywords: MuSIASEM, HJ-Biplot, sustainability, sustainable development, Spain, water use, water-energy-food nexus.

1 INTRODUCTION

Since some years ago, scientists around the world have been warning of the climate change consequences. Rising temperatures, biodiversity loss or ecosystem changes are some examples that have been forecasted by numerous studies, leaving as a consequence a hopeless future for the generations to come.

In this context, water sustainability is one of the biggest problems caused by climate change. In 2005, the Spanish Government elaborated an inform called Preliminary Assessment of Climate Change Impacts on Spain [1], trying to predict what essential changes will be produced by climate change in this country in the coming years. In addition to many other things, this study talks about a sharp decline in the country's water resources, emphasising that some of them could even disappear. Also, water is an indispensable element for life as we know it. Not only is it needed directly by people daily to survive, but everything that surrounds us needs water to be carried out, from the food consumed daily to cars or clothes.

Consequently, the quest for water sustainability is becoming an increasingly vital necessity. In 2014, the Food and Agriculture Organization of the United Nations (FAO) defined the Water-Energy-Food Nexus (WEFN) as the element responsible for linking the interactions between humans and natural systems. This concept encompasses socio-economic and biophysical resources needed to achieve social, environmental and economic objectives related to water, energy and food [2].

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In this way, FAO and other scientific research recommend using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach to study this nexus. This accounting method, developed by Giampietro and Mayumi in 2000 [3], can integrate quantitative information obtained through different models based on various dimensions and scales of analysis [4]. Thus, MuSIASEM is able to take into account environmental and social-economic dimensions in a single analysis.

Therefore, the nexus study can provide very revealing information about the sustainability of natural resources in a territory. Numerous studies based on the MuSIASEM approach have already been carried out in other parts of the world, such as China [5], Chile, Brazil and Venezuela [6] or Ecuador [7]–[9]. In addition, there is research in the latter country where multivariate techniques are also applied to enrich the MuSIASEM research, such as the HJ-Biplot or the use of GWPCAs [10]. Likewise, numerous studies have also been carried out in Europe applying this methodology, such as in the United Kingdom [11] or Romania, Bulgaria, Poland and Hungary [12]. Recent research using the MuSIASEM technique can even be found in Spain [13], [14]. However, most of these investigations are carried out by an approach in which energy and its use is the main subject of study. This research will attempt to situate another element of the WEFN in focus, trying to achieve a novel and enlightening approach to water sustainability in Spain in 2018.

2 MATERIALS AND METHODS

2.1 A case under study: Spain

Spain is the fourth most populated country in the European Union and is one of the strongest economies in the world. It also has a regressive or bulbous pyramid, characteristic of developed countries [3]. Spain occupies most of the Iberian Peninsula of Europe and two island territories and two cities in North Africa. It is surrounded by the Cantabrian and Mediterranean Seas and has some direct access to the Atlantic Ocean. Territorially, the country is divided into 17 autonomous communities plus two autonomous cities located in North Africa (Ceuta and Melilla). These 19 territories have a certain legislative autonomy that is unusual in neighbouring countries. Thanks to this decentralisation, Spain can boast multiculturalism that is not typical of such a small territory.

Due to its geographical situation and climatic and cultural differences, Spain is an extremely interesting country to analyse using the MuSIASEM technique. By studying sustainability in such a diverse country, many valuable conclusions can be drawn to develop further and improve the use of aquatic resources in this territory. In this way, Spain has been divided into 18 territories; 17 Autonomous Regions and one domain consisted of two Autonomous Cities: Ceuta and Melilla. Likewise, it has been preferred to analyse only the part related to water use within the WEFN since, as previously explained, Spain's geographical situation makes it a highly interesting country to analyse this element. Both the socio-economic variables and the variables related to water use have been obtained from data provided by the Spanish national statistics institute for 2018.

2.2 MuSIASEM: Multi-scale integrated analysis of societal and ecosystem metabolism

The first method used in this study to analyse water sustainability in Spain in 2018 is the MuSIASEM approach. This model can deal with different hierarchical levels and scales, making it a highly useful technique for studying possible links between variables in other areas [3]. Also, the MuSIASEM method can recognise and characterise the existing metabolic pattern in the socio-economic system, providing extensive information on the different elements (flow and funds).

This technique is essentially based on applying four main theoretical ideas; the flow-fund model, the multi-level/multi-scale accounting, the multi-purpose grammar and the impredicative loop analysis [4]. The flow-fund conceptual model, developed by Georgescu-Roegen in 1971 [15], allows the socio-economic processes of consumption and production of goods and services to be represented in biophysical terms. On the one hand, the funds are those elements that do not vary throughout the study; in other words, they are used, but they are not consumed and tell us "what the system is made of". On the other hand, the flows represent "what the system is doing", and they tend to change during the study, appearing or disappearing [4]. Furthermore, multi-level accounting represents the different hierarchical levels of analysis (level n, n-1, n-2, etc.), while multi-scale accounting refers to the different types of variables involved in the analysis (biophysical, economic, etc.) Also, the grammar provides a description based solely on the relations between semantic categories. Thus, a set of relations is created between formal and semantic categories, due to which grammar is semantically open (the same term can be defined in several ways). Finally, it is convenient to formalise this grammar in quantitative terms by eliciting a set of congruence relations between the characteristics of the parts and those of the whole. These links imply that the characteristics of the components must be compatible with those of the total and vice versa but need not define a linear causal relationship between them [4].

Twenty-one MuSIASEM variables will be analysed for 18 individuals or territories at three different levels (n, n-1 and n-2) in this study. First, a general level n will be defined, where the variables that affect society will be found. Subsequently, there is a level n-1, divided into two large groups known as paid work (PW) and household (HH). The first sector, PW, is responsible for generating the entire GVA or GDP of a society. In contrast, the second sector, HH, not only does not produce any economic value but is also responsible for consuming these values [13]. However, both sectors make equal use of the element water to exist and develop. Finally, a level n-2 is defined where the paid labour sector (PW) is further subdivided into two sectors: the economic sector (EC) and the government sector (GOB). In this way, a division is made between the public and the private sector.

2.3 HJ-Biplot method

To extend and enrich the analysis of the WEFN in Spain, following the MuSIASEM approach, it has been decided to use multivariate techniques, applying the HJ-Biplot method to the database. This method, proposed by Galindo in 1986 [16], is just a variant of the biplot methods proposed by Gabriel in 1971 (GH-Biplot and JK-Biplot) [17]. However, unlike these methods, the HJ-Biplot can achieve maximum representation for both rows and columns when represented on a low dimensional vector dimension. Thus, the HJ-Biplot method can perform a multivariate representation of row and column markers chosen so that they can be superimposed on a standard reference system obtaining maximum quality of representation [18].

Formally, a biplot is a graphical representation of an initial data matrix, X (IxJ), employing markers $a_1, a_2, \ldots, a_I$ for the rows of X and $b_1, b_2, \ldots, b_J$ for the columns of X, such that the scalar product $a_i^T b_j$ approximates the element x_{ij} as well as possible. Furthermore, considering the markers $a_1, a_2, \ldots, a_I$ as the rows of a matrix A and the markers

$b_1, b_2, \ldots, b_J$ as the rows of another matrix B, it is possible to state that: $X \cong AB^T$. Also, the starting matrix with dimension IxJ, where, in general, the I rows correspond to the individuals and the J columns to the variables, and with a rank r, must be approximated to another with a lower rank q ($q < r$). This will be achieved through the Decomposition into Singular Values (DVS) and Singular Vectors of X [19]: $X = UDV^T$, where X (IxJ) is the original data matrix with rank r, U (Ixr) a matrix whose column vectors are orthonormal and contain the eigenvectors of XX', V (Jxr) is the matrix whose column vectors are orthonormal and contain the eigenvectors of $X'X$ and D (rxr) is the diagonal matrix containing the eigenvectors of X. Moreover, U and V must be orthonormal, i.e. $UU' = V'V = 1$. In this way, the factorisation is guaranteed to be unique since this is not always the case. Therefore: $X = AB^T = UDV^T$.

Table 1: Resumé of the variables MuSIASEM used. *(Source: Own elaboration.)*

Variable (unit)	Complete name	Calculation	Flow or Fund	Description
THA (hr)	Total human activity	Population × 8,760 hours per year	Fund	Total of hours of human activity in a society
HA_i (hr)	Human activity in sector i	People employed per sector × hours of work per week × 52 weeks of work per year	Fund	Total of hours spent in each sector
GVA (€)	Gross value added	Taken directly from INE	Flow	Added value generated by an economy in one year
GVA_i (€)	Gross value added in sector i	Taken directly from INE	Flow	Added value from the various sectors
ELP_i (€/hr)	Economic labour productivity for sector i	GVA_i/HA_i	Flow/Fund	Added value per hour of working time in activity i
GWU (l/hr)	Gross water use	Taken directly from INE	Flow	Gross use of water appropriated by society, including losses and unaccounted-for water.
NWU_i (l/hr)	Net water use for sector i	Taken directly from INE	Flow	Net water use according to the different sectors.
WMR_{SA} (l/hr)	Water metabolic rate, average of the society	GWU/THA	Flow/Fund	Total amount of water used per hour of human activity
WMR_i (l/hr)	Water metabolic rate for sector i	NWU_i/HA_i	Flow/Fund	Amount of water used per hour of human activity spent in each sector

In this case, the matrix that will be analysed (IxJ) is formed by 18 individuals (territories within Spain) and 21 MuSIASEM variables, which are shown in Table 1. The BiplotbootGUI package [20] in Rstudio will be used as a development tool for this technique. The result is a Euclidean map in reduced dimension (2D) where the variables or columns are represented by vectors and the individuals or rows as points in the same reference system. For this reason, the geometric interpretation of this representation is based on simple geometric concepts; the cosine of the angle formed by two vectors indicates the degree of correlation between these variables, the smaller the angle, the higher the correlation ($\cos\theta \propto r$); the distance between individuals indicates the dissimilarity between them, the greater the distance, the greater the dissimilarity; lengths of column vectors indicate the standard deviation of the variables, the longer the vector, the more variability the variables collect and, therefore, the more information it will provide.

3 RESULTS

3.1 MuSIASEM analysis: Graphical description

This section will obtain graphical representations of the 21 variables individually to interpret the results better.

3.1.1 AH, VAB and UW variables

At all levels of study, it can be observed that all variables related to water use, human activity and gross value added to have a greater weight in the territories with a more significant number of inhabitants. The four Spanish regions with the most significant number of inhabitants (Andalusia, Catalonia, Madrid and Valencia) occupy the first four positions in these 13 variables. These territories represent the most populated areas with the largest populations in the different sectors and the regions that produce the most money and consume the most water within the Spanish territory.

THA, HA_{HH}, HA_{GOB}, GWU, NWU_{PW}, NWU_{HH} and NWU_{EC} have their maximum in Andalusia, while HA_{PW}, HA_{EC} and GVA_{GOB} have their maximum in Catalonia. Finally, the variables NWU_{GOB} and GVA and GVAEC take their maximum value in the community of Madrid (see Figs 1 and 2).

Moreover, all these variables have their minimum in Ceuta and Melilla, La Rioja and Cantabria. All of them have their minimum in the autonomous cities of Ceuta and Melilla, except VAB_{GOB} and NWU_{GOB}, which have them in La Rioja and Cantabria, respectively. Thus, it is confirmed that the territories with lower populations have a lower weight in these indices.

Therefore, it is confirmed that the variables related to HA, GVA and WU are directly related to the number of inhabitants in the territories or exercising a specific activity. This reasoning makes sense since the greater the number of inhabitants, the greater the human activity, the greater the GVA, and, in turn, the greater the water use.

3.1.2 ELP variables

Suppose we now study the variables related to economic labour productivity. In that case, we can see that these three variables take high values in the same four territories: Madrid, the Basque Country, Catalonia and Navarre. In ELP_{PW} and $ELP_{GOB,}$ the maximum is found in the Basque Country, while in ELP_{EC} the most is located in Madrid (see Fig. 3).

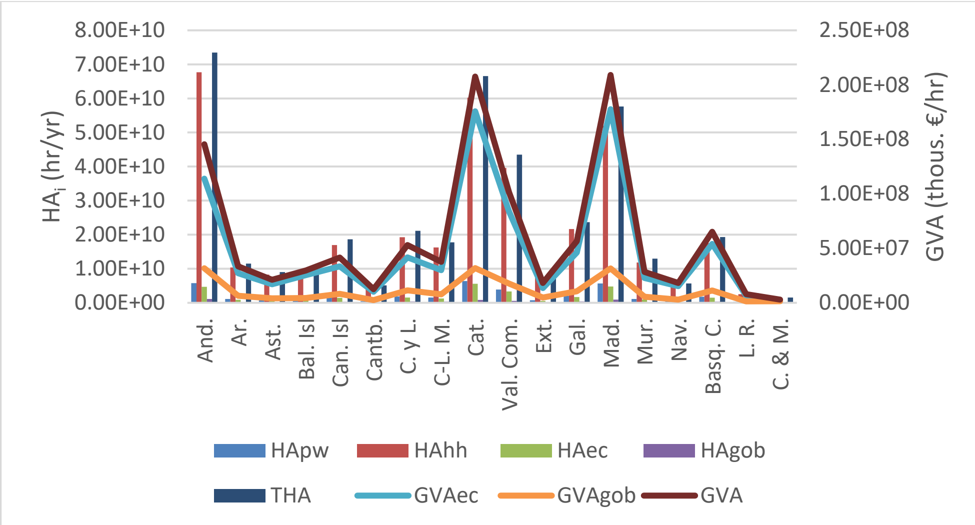

Figure 1: HA and GVA variables of the different territories of Spain.

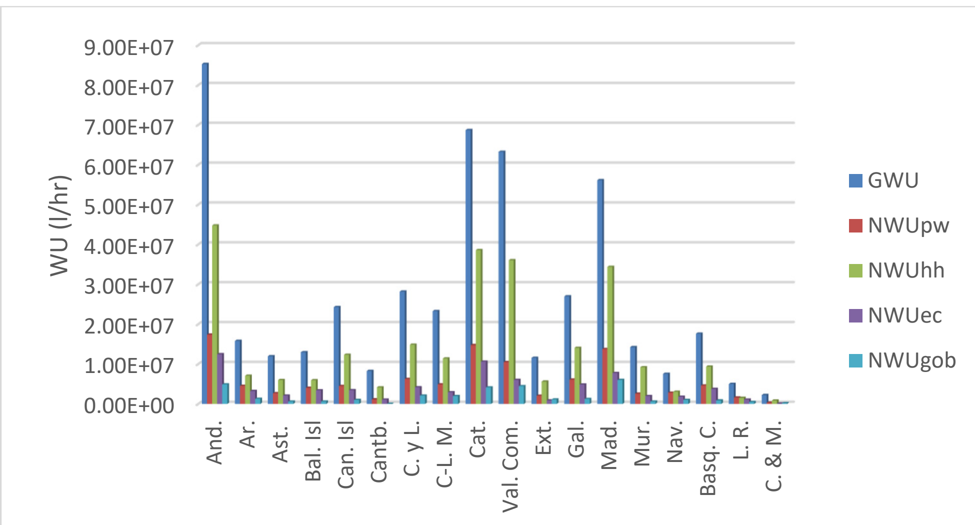

Figure 2: WU variables of the different territories of Spain.

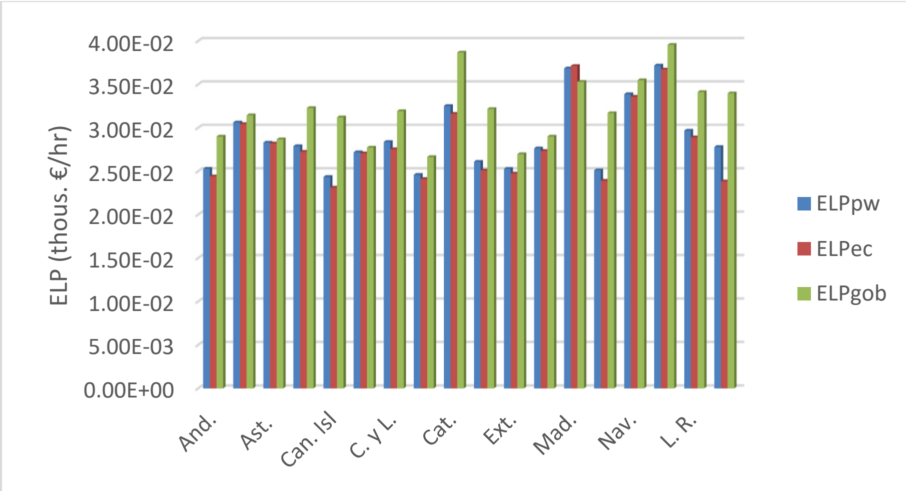

Figure 3: ELP variables of the different territories of Spain.

3.1.3 WMR variables

Finally, we must study the variables related to the metabolic rate of water. In this case, unlike the previous ones, we do not see the uniqueness in terms of the territories in which these values are maximum, but rather it depends significantly on the variable in question.

The territories with the highest values for the WMR_{SA} variables are La Rioja, Cantabria, Ceuta and Melilla and Valencia. In contrast, the territories of La Rioja, Navarra, Aragón and the Balearic Islands have high values for the WMR_{PW} and WMR_{EC} indicators. Finally, WMR_{HH} takes high values in Valencia, Cantabria, Murcia and Castilla y León while WMR_{GOB} in La Rioja and Navarra (see Fig. 4).

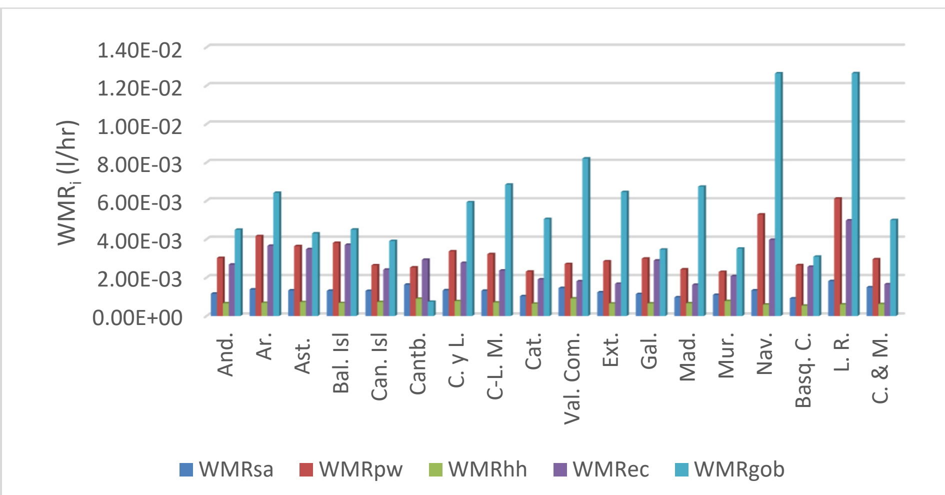

Figure 4: WMR variables of the different territories of Spain.

3.2 HJ-Biplot method

After having thoroughly analysed the 21 MuSIASEM variables, it is possible to complement and considerably extend the study of these data by applying a multivariate technique such as HJ-Biplot to the database (18 individuals and 21 variables). In this way, the first thing that can be observed is that the first three axes can capture 90% of the total variability of the analysis and the first two axes more than 80% (see Table 2). Consequently, it is possible to assume that a two-dimensional solution will be sufficient to explain the various characteristics of the data set.

Table 2: Eigenvalues and % variance explained.

Axes	Eigenvalues		% of variance	% Cumulative variance
1	15.11		63.98	63.98
2	7.7		16.59	80.57
3	5.82		9.44	90.01

On the other hand, by plotting the variables and individuals in the same two-dimensional reference system, we can observe results similar to those obtained with the previous analysis. First, we see a clear dependence between the variables related to HA, WU and GVA. All these variables, located on the left side of the representation, have a solid and direct correlation, forming small angles between the vectors. In the same way, Fig. 5 shows a strong dependence between the ELP variables in the upper part of the representation. All these variables form small angles to each other and are therefore strongly and directly correlated. Finally, we can see how the rest of the variables are somewhat more scattered on the right side of the representation. In addition, we can see how the WMR_{EC} and WMR_{PW} variables are strongly correlated with each other.

If we then look at the groupings formed between individuals and assuming that the shorter the distance between them, the greater the degree of similarity, we see how three clusters can generally be formed. The four territories will create the first of these, with the most significant inhabitants in Spain (Andalusia, Catalonia, Madrid and the Valencian Community). This first cluster is located on the left side of the representation. We can see how while Madrid and Barcelona are located above axis 2 very close to each other, the other two are located below the axis somewhat further away. This is quite significant since these four territories are placed quite far away from the rest, especially Madrid, Barcelona and Andalusia, so it is expected that these territories share specific characteristics and differ significantly from the rest.

On the other hand, we can find a second cluster formed by the territories of the Basque Country, Navarra, Aragón and La Rioja in the upper right part of the graph. All these territories share the same geographical location; they are all located in the north-eastern part of the Iberian Peninsula (see Fig. 6). Finally, the rest of the territories form a third cluster located in the lower right part of the representation. Within this grouping are territories such as Galicia or Castilla y León, which are located very close to the centre of coordinates and, therefore, do not contribute much information to the analysis. In the same way, Fig. 5 shows how the variables WMR_{GOB}, WMR_{SA} or WMR_{EC} have shorter vectors than the rest of the variables and, therefore, contribute less information to the analysis. However, in general, it can be assumed that all variables are perfectly represented in this 1–2 plane.

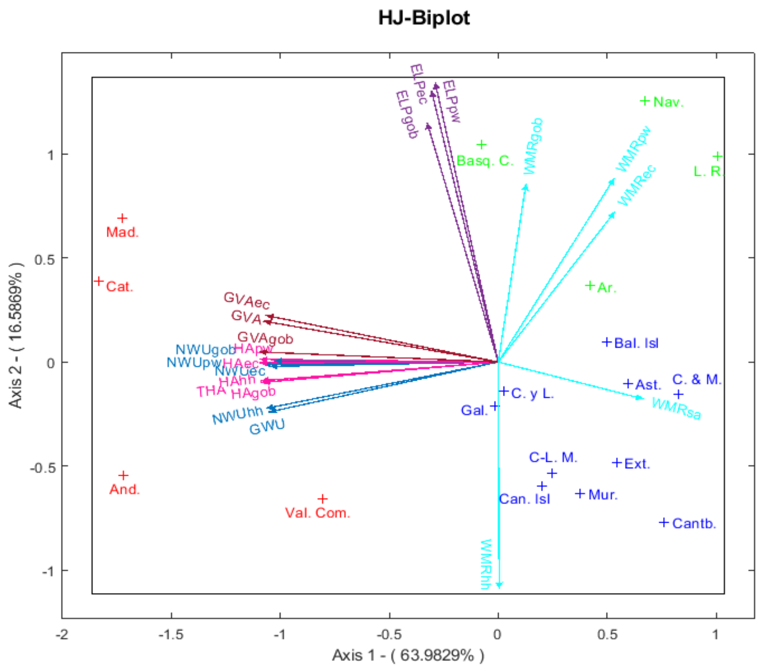

Figure 5: HJ-Biplot representation of the 18 territories and the 21 variables.

Figure 6: Clusters of Spain.

Finally, the interaction of the 18 individuals and the 21 MuSIASEM variables should be studied. In this case, the results are entirely similar to those obtained with the analysis of the descriptive statistics of the 21 variables individually. Thus, a greater weight of the variables related to water use, human activity, and gross value added is visualised in the populations of the first cluster, i.e. the populations with the most significant number of inhabitants. Secondly, we see how the variables related to ELP are at their highest in the Basque Country, Navarre, Madrid and Catalonia, as previously deduced. In addition, the representation shows how certain territories of the third cluster, such as Cantabria and La Rioja, have high values in most of the WMR-related indicators.

4 DISCUSSION

Thanks to the multivariate HJ-Biplot method, we have considerably enriched the MuSIASEM analysis of water sustainability in Spain. The application of the multivariate method to the database (18x21) allows us to represent in the same two-dimensional plane both the MuSIASEM variables and the territories within the Spanish state and the interactions between both groups.

This combination of methods reveals, in the first place, the fact that the four territories with the largest populations behave similarly. The first cluster of individuals takes high values in all variables related to water use, human activity, and gross value added. Moreover, these variables are strongly and directly correlated. Secondly, we can see a clustering of the three variables related to ELP. All of them have a strong dependence and take high values in the territories of Madrid and Catalonia, in the first cluster, and the Basque Country and Navarra in the second cluster. Finally, the variables related to WMR in paid work and the economic sector are highly correlated. However, the rest of the variables in this group are somewhat more separated from each other, denoting certain independence.

If we focus on water use in Spain, which is the ultimate goal of this research, we can draw several implications. First, we can see a typical result in all the variables except the variable relating to the household; the maximum in all these variables is in La Rioja. In addition, Navarre occupies second place in the WMR_{PW}, WMR_{EC} and WMR_{GOB} variables. On the other hand, WMR_{HH} has its maximum in Valencia, followed by Cantabria, which also occupies second place in WMR_{SA}. Observing these results, it can be seen that certain territories have high values in the indicators related to WMR but low values in the rest. This shows the existence of certain territories where excessive and disproportionate water expenditure is being made in specific sectors that could be easily solved without considerably disrupting the functioning of society. The first clear example of this would be La Rioja, which consumes the most litres of water per hour of human activity in four out of five variables related to WMR. Other examples could be Cantabria in the WMR_{SA} and WMR_{HH} variables, the Balearic Islands in PW and the EC sector, or Castilla y León and Murcia in the HH sector. This should be studied later in a more extensive investigation to analyse why certain areas consume more water within Spain and whether it is possible to reduce this expenditure.

This analysis also shows no evidence of a solid and direct correlation between the metabolic rate of water consumed in the labour sector and the economic productivity of labour. This clashes head-on with previous research on energy use in different territories. In 2001, Jesús Ramos-Martín showed how in Spain, a strong correlation between the variables ELP_{PW} and EMR_{PW} can be verified, the latter being the variable in charge of representing the exosomatic energy rate for the paid labour sector [13]. During this research, it is shown that the hypothesis formulated by Cleveland et al. [21] and Hall et al. [22] about the correlation between these two variables is also true for the case of Spain. Therefore, a direct relationship between hourly electricity consumption in paid work activity and the amount of GVA generated in this sector per hour of human activity was demonstrated, associating higher energy expenditure with higher economic productivity of labour. However, the results obtained during this study imply that this situation cannot be generalised in the case of water in Spain, since there is no strong and direct correlation between the WMR_{PW} and ELP_{PW} variables.

5 CONCLUSIONS

Taking into account all the considerations obtained throughout the research, it is possible to draw certain conclusions that are worth mentioning and recapitulating:

1. Both techniques are capable of perfectly studying the sustainability in a given territory. In this way, a successful study on water use in Spain in 2018 has been carried out.
2. The MuSIASEM approach manages to define the database that will be subsequently explored effectively. Thanks to this analysis, it is possible to get a detailed report of the territories that excel in specific indicators, denoting the socio-economic characteristics and water use in those territories.
3. The MuSIASEM grammar opens the way to a new way of exploring sustainability in the different countries of the world, inspecting as many levels and elements as desired.
4. The HJ-Biplot analysis has considerably expanded the knowledge about sustainability in the territory under study. This new approach offers in a much more visual, straightforward way the different interactions between places and indicators and the internal correlations existing in both groups.
5. The use of both techniques has meant a different approach, but at the same time, a sample of absolute concordance, obtaining widely coherent and equivalent conclusions.
6. Most of the research on sustainability using the MuSIASEM approach has been done by focusing on energy use in a given territory. However, this study shows how water is a perfect candidate to be studied with this technique.
7. A strong and direct correlation between the metabolic rate of water in paid work and economic labour productivity in this same sector cannot be assumed.
8. Many of the territories in the third cluster, such as Cantabria, La Rioja, Murcia, Ceuta and Melilla or Castilla y León, have high values for the WMR variables but low values for the rest of the variables, which can be interpreted as an excess of water expenditure that could be easily solved without considerably disrupting the functioning of society.

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