ENERGY SUSTAINABILITY: MACROECONOMIC INDICATORS AND PRODUCTIVE SECTORS

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1. INTRODUCTION.

As a starting point, the approach to sustainable energy strategies must be undertaken based on a series of fundamental principles. Reliability and quality of supply is a basic concept to meet energy demands, which in turn is gaining momentum at the pace of technological development. On the other hand, it must also respect the environment and biodiversity in response to the impact produced by the use of energy in any of its forms. Driving a sustainable economy needs to take into account the efficiency of processes, organizations and individuals as well as social responsibility of the productive sectors, as generators of employment. Finally, we must guarantee social equity in all its forms, with universal access to energy at reasonable costs, while boosting energy markets, making them more efficient and competitive.

The problem lies mainly in the determination of the variables that should be monitored, but first, the suitability of the different economic, energy, territorial and social situations of the different territories must be questioned, that is, not all the variables will be the most suitable for carry out an analysis of the energy situation in the different nations taking into account the concept of local sustainability [1]. Therefore, we should no longer be talking so much about energy sustainability variables, but about families of sustainability variables that will be suitable for the particular situations of different nations.

The model is developed based on three major decision areas: environment (emissions and pollution), economy (growth) and society (energy demand), which, when descending in the analysis to the energy sustainability subsector, two basic energy aspects take on great importance: reliability of supply and regulation of markets. Based on these five main areas, a model of indicators is constructed to monitor energy sustainability compliance in different nations. However, different thresholds are set that will determine the degree of compliance of the countries, and ratios of specific energy variables and competitiveness and productivity will be established.

There are other models of indicators, proposed by different organizations for monitoring data on an international level [2] and [3]. Many of them are complementary and are a great help when it comes to decision-making in the energy field. The most relevant to the energy component that concerns us are the following: World Energy Council model (WEC - Energy Trilemma), the International Atomic Energy Agency model (IAEA), the Energy Indicators for Sustainable Development model (EISD), the International Energy Agency model (IEA - OECD) and, finally, a model further removed from the energy vector, but interesting for how it handles the concept of sustainability: the Sustainable Development Goals (SDG - United Nations).

2. PREMISES FOR A MODEL OF ENERGY SUSTAINABILITY INDICATORS.

It should be based on three fundamental premises. The first premise lies in the use of the weak sustainability paradigm [4], as the only possible approach for developing a conceptualization that takes into account the transversal force of technology [5], which allows the limits of natural capital to be extended and make it unlimited while substitutable, the latter aspect that, through the strong paradigm of sustainable development is not possible to reason because it entails short-lived and limited natural capital. Therefore, the dissociation between the three aspects of sustainable development could also only be conceived through the paradigm of weak sustainability in the conceptualization of sustainable development.

The second premise is that energy sustainability underlies sustainable development, that is, energy sustainability is in a different layer to that defined by the three dimensions of sustainable development: economy, environment and society. There will be no sustainable development without energy sustainability that allows such development (also coexisting with the subsystems: territorial management, management of the atmosphere and air quality and water resource management) [6]. Therefore, for sustainable development to exist, there must also be such sustainability in the four subsystems around the three dimensions (Figure 1).

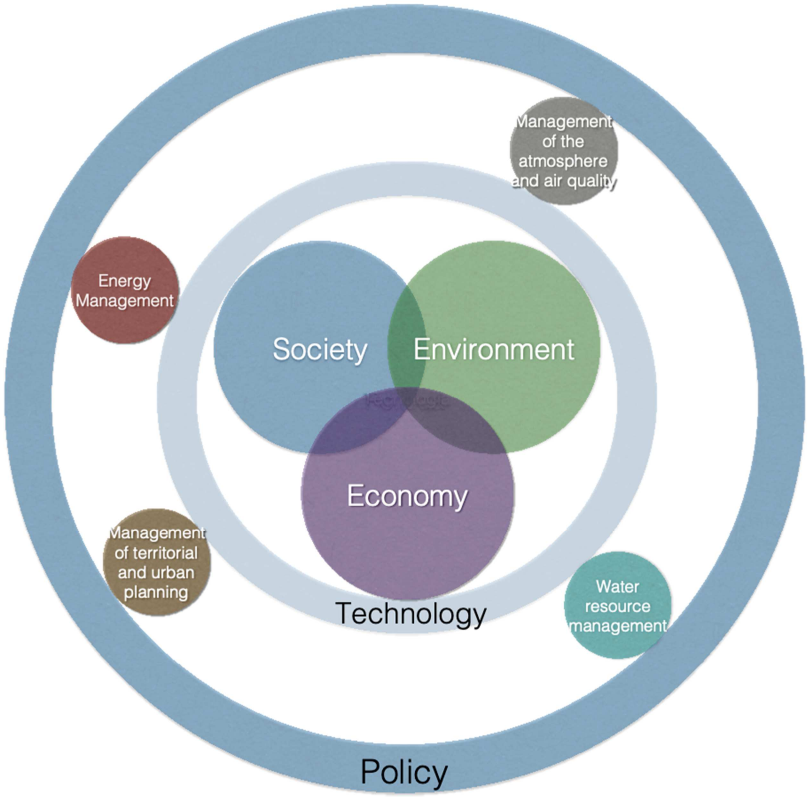

Figure 1. Contextualization of energy sustainability.

The third premise consists in the suitability of the indicators to the different economic, energetic, territorial and social situations of the different territories, that is, not all the indicators will be the most suitable for carrying out an analysis of the energy situation in the different nations, taking into account the concept of local sustainability [1], since they can draw conclusions and define policies that will not be replicated.

The indicators defined here are therefore adapted to a particular energy, territorial, social and economic situation. Satisfying the evaluation, for example, of vulnerable spaces, rural areas in developed countries, or industrial areas and their impact on biodiversity, should be defined through new indicators, perhaps focused on more operational variables such as biomass consumption, degree of depopulation or even deforestation rates, an aspect that goes beyond the scope of this paper.

3. GOVERNANCE FRAMEWORK FOR ENERGY SUSTAINABILITY.

Therefore, if we move the analysis of the three dimensions of sustainable development towards its homologous descriptors in the field of energy sustainability, the indicators are framed within three main areas: emissions and pollution (environment), growth (economy) and energy demand (society), and, as will be explained at the end of the paper, will serve to validate the model through the dissociation of variables belonging to these three large dimensions. On the other hand, descending in the analysis to the subsector of energy sustainability, the following elements take on greater importance: reliability of supply and market regulation.

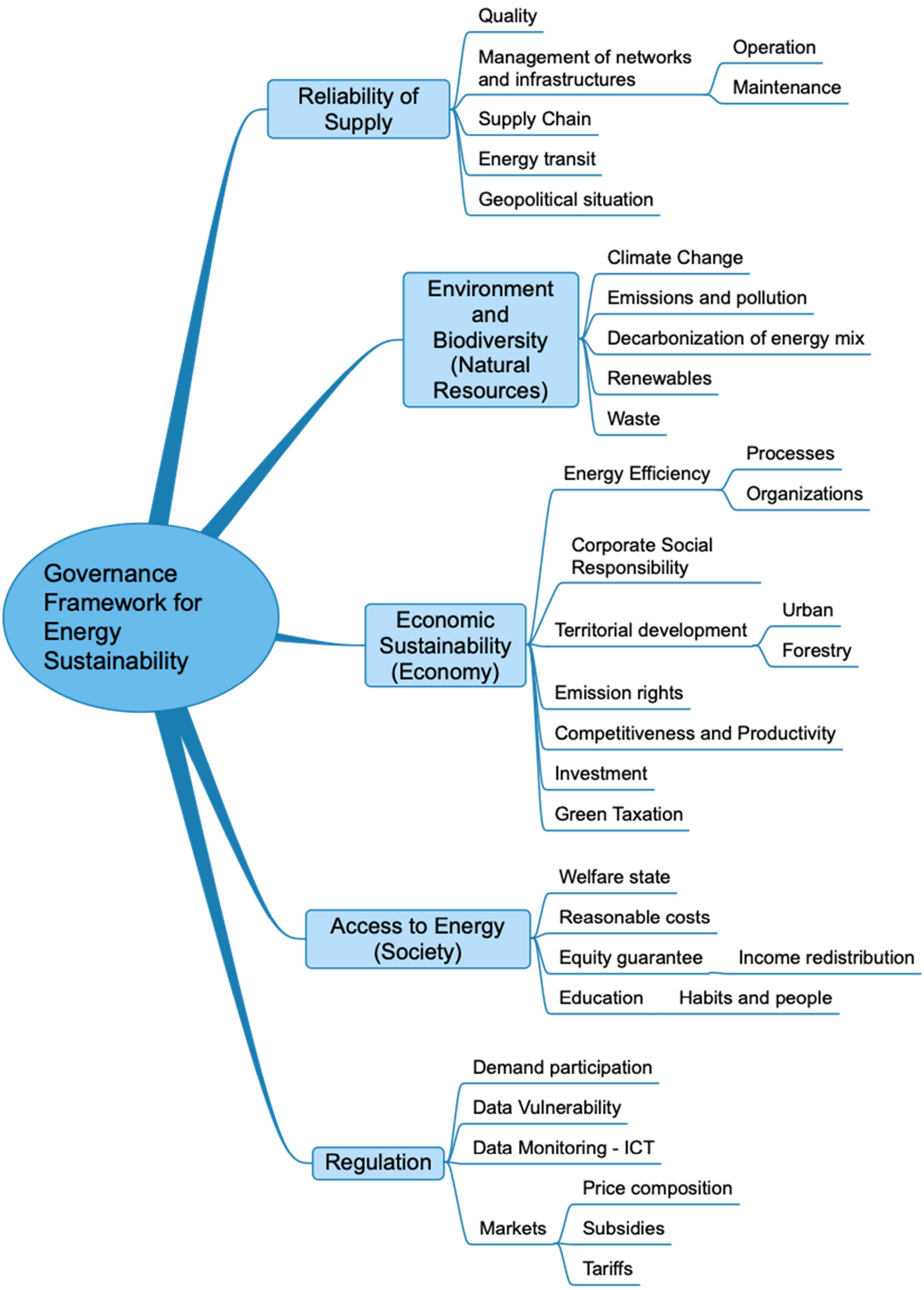

Figure 2. Governance framework for energy sustainability.

As can be seen in Figure 2, two new areas must be taken into consideration in decision-making for governance: on the one hand the concept of reliability of supply, of strategic importance for the energy sector and which forms the base of important areas covering energy transit, supply logistics, technical management of networks and infrastructure, the quality parameters established for each of the different forms of energy, and most importantly, as an indicator and fundamental concern of the energy policies of many European countries: the **Degree of Energy Self-sufficiency or Dependence on Foreign Energy Sources**, which will be the main variable to be considered in the model.

On the other hand, regarding market regulation, the instruments of sustainable energy management acquire great relevance: from the wholesale level with the pricing structure from the offer, to the retailer with the regulation of the access rate or the demand management formulas in the different energy intensive sectors (transport, industry, trade, services, construction, ...). While it is true that there are still many questions regarding how the management of information will affect the behavior of markets and new regulatory scenarios (self-supply), without a doubt, the electricity sector will benefit most from a great revitalization through good management of existing technologies that can lead to a new paradigm. Therefore, the **Technical Intensity of the energy system** can be defined as a fundamental aggregation indicator.

The third major area of governance for energy sustainability entails the protection of the environment and the climate in all its aspects, which includes all those actions that should make our biodiversity sustainable: monitoring the consequences of climate change, promoting the reduction of emissions and pollution, driving the decarbonization of the energy mix, developing energy from renewable sources, defining new waste recycling policies, and implementing and developing environmental management tools such as the Ecological Footprint. Therefore, there should be an aggregate indicator, which in this case will be taken into account for its diversification and for its international recognition: **CO2 Emission Intensity**.

The fourth major area, the sustainable economy, covers actions to boost investment, territorial and water policy, policies governing efficiency, taxation, financial aspects and the improving the competitiveness of companies that will allow a stable framework to promote investments, especially, from the private sector. But also they require efforts on developing products and services that take into account the entire life cycle from conception and design through to its disposal, requiring a culture of efficiency at all levels. To monitor this important area, the parameter that will determine the disaggregation in the energy paradigm will be the **Energy Intensity of the Economy**.

The fifth major area, that of society and access to energy in equity, is the core of sustainable development since without access to energy there can be no human progress, much less if it occurs under conditions of unsustainability. It is important to remember that there are great contrasts in the world in relation to access to energy. Finally, we highlight the United Nations initiative on the 17 Sustainable Development Goals [2], which includes ensuring access to affordable, reliable, sustainable and modern energy for all. Among others, as the main indicator on which to establish disaggregation it will be very appropriate to determine the **Social Progress Index** corrected by the Human Development Index (HDI), as being representative in this area.

4. SELECTION OF COUNTRIES ANALYZED. PRIOR CONSIDERATIONS IN THE INDICATORS.

A variable interpreted in isolation can lead to error, for example, regarding the Energy Intensity of the Economy, countries like Nigeria, Kazakhstan or Zambia have the highest rates in the world, but in other areas (human rights, employment, technological development, welfare state) are far behind other developed countries with much lower energy intensity rates [1]. It is also important to observe the indicators in relative terms: energy consumption per capita, energy intensity of the economy, intensity of emissions, GDP per capita, etc. ..., which will be very suitable for comparisons between nations.

Furthermore, given the existence of very differentiated geopolitical aspects in other continents such as varying degrees of environmental commitments or the different level of protection of human rights, the analysis should be framed in a specific continent of reference.

Finally, the territorial situation perspective will also be taken into account: the transport and mobility model, population aspects (per capita housing area, residential and tertiary sector), GDP distribution, and aspects related to the level of technology use, which will also establish similarities by applying the concept of local sustainability, which will facilitate the comparison of indicators and obtain patterns of behavior according to the following variables.

- Population,
- GDP and GDP per capita,
- Contribution of productive sectors to GDP,
- Transport activity: transport model, distance traveled per capita,
- Housing area per capita,
- Gross value added manufacturing or other economic sectors.
- Access to electricity and water by the population (%),
- Energy affordability (US $ / kWh)
- Wage inequality or poverty level
- Health, educational and social services coverage
- State of infrastructure and communications
- Situation regarding defense and human rights
- Energy intensity of the economy (ktep / US $)
- Emission intensity (kCO2 / US $) emissions per capita (kCO2 / per capita)

Therefore, comparable countries will be those that have their situation parameters framed in clusters based on the previous variables. The range of nations defined for the study and based on these parameters are: Germany, France, Italy, United Kingdom and Spain.

5. DEFINITION OF INDICATORS. GENERAL INDEX OF ENERGY SUSTAINABILITY.

In the previous sections, a general description has been made of all the variables that frame a set of indicators that represent energy sustainability from the dimensions of sustainable development. This section establishes the formulation of the General Index of Energy Sustainability [6].

The mathematical expression that defines the General Index of Energy Sustainability Index and that adds all the general indicators once standardized is the following:

$$GIES_t^i = \frac{EIE_t^i}{140} + FED_{EU}{}_t^i + \left(100 - TI_{ES}{}_t^i\right) + \frac{GHG_{GDPt}^i}{0{,}4} + \left(100 - SPI_C{}_t^i\right) \qquad (1)$$

Where:

$GIES_t^i$, General Index of Energy Sustainability

EIE_t^i, Energy Intensity of the Economy (ktep/€)

$FED_{EU}{}_t^i$, Foreign Energy Dependence (%)

$TI_{ES}{}_t^i$, Technical Intensity of the energy system (%)

Defined as $TI_{ES} = \frac{Final\ \ Energy\ Consumption\ (ktep)}{Primary\ Energy\ Consumption\ (ktep)}$

$GHG_{GDP}{}_t^i$, Intensity of GHG emissions (kgeCO$_2$/€)

$SPI_C{}_t^i$, corrected Social Progress Index (%)

The standardization of indicators [6] is carried out in order to achieve their aggregation in a General Index of Energy Sustainability (GIES) with the following criteria: a lower index will correspond to greater sustainability, that is, the lower the indicator, the higher sustainability.

Following this reasoning, the indicators have been standardized according to the following criteria:

A. Indicators that already expressed a decreasing percentage value indicative of improvement of sustainability: no standardization is established.
B. Indicators that expressed an increasing percentage value indicative of improvement of sustainability: the investment is established according to the expression (100-Xi) where Xi is the indicator without standardization.
C. Indicators that expressed the value of the variable they represented: the maximum observation range is established over which a percentage ratio is established.

Criterion for standardization	General indicator	Range	Expression of Standardization
A	FED_{EU}	-	FED_{EU}
C	EIE	90-140	EIE/140
B	TI_{ES}	0-100	$100-TI_{ES}$
C	GHG_{GDP}	0.15-0.40	$(GHG_{GDP})/0.4$
B	SPI_C	0-100	$100-SPI_C$

Table 1. Standardization of GIES indicators

Finally, the following table shows the final values of the General Index of Energy Sustainability (GIES) for the 2014-2017 period. The best sustainable behavior is performed by the United Kingdom, followed by France and Italy. At the tail of sustainability, we would have Germany and Spain.

2014	Germany	Spain	France	Italy	United Kingdom	2015	Germany	Spain	France	Italy	United Kingdom
FEDeu	61.94	72.75	46.24	75.81	46.77	**FEDeu**	62.23	72.94	46.00	77.03	37.50
EIE/140	82.00	87.26	88.60	70.26	67.83	**EIE/140**	81.14	87.09	89.04	72.31	67.56
100-TI	28.65	30.64	40.05	20.57	28.00	**100-TI**	28.20	32.24	39.94	22.06	27.53
GHG_{GDP}/0.4	72.61	68.27	42.31	54.24	53.38	**GHG_{GDP}/0.4**	69.99	70.15	41.35	54.16	44.69
100-SPIc	18.15	24.23	20.45	25.26	20.10	**100-SPIc**	18.00	23.94	20.37	25.06	20.13
	263.35	**283.15**	**237.65**	**246.14**	**216.08**		**259.55**	**286.36**	**236.69**	**250.62**	**197.42**

2016	Germany	Spain	France	Italy	United Kingdom	2017	Germany	Spain	France	Italy	United Kingdom
FEDeu	63.71	71.49	47.36	77.65	35.68	**FEDeu**	63.91	73.94	48.59	76.98	35.35
EIE/140	80.11	85.32	86.53	70.99	65.41	**EIE/140**	79.04	86.36	84.78	72.19	63.11

100-TI	27.20	30.84	38.10	21.66	25.24	**100-TI**	26.68	32.87	37.81	22.67	24.58
GHG_{GDP}/0.4	67.20	63.92	40.22	52.21	45.41	**GHG_{GDP}/0.4**	63.85	63.75	40.01	50.85	45.53
100-SPIc	17.67	23.60	20.11	24.85	19.55	**100-SPIc**	17.60	23.29	20.00	24.24	19.71
	255.89	**275.17**	**232.31**	**247.35**	**191.29**		**251.08**	**280.22**	**231.19**	**246.92**	**188.29**

Table 2. Summary of GIES results for the years 2014-2017

6. DISSOCIATION OF THE THREE PILLARS. VALIDATION OF THE MODEL.

It is widely recognized that sustainable development consists of three closely related dimensions: environment, economy and society [7] and [8], where any variation in one of them significantly affects the other two [9] and, moreover, they are closely interrelated.

Therefore, the fundamental premise of sustainable development will be to decouple that dependence and, therefore, a variation in one of the dimensions will influence the development and evolution of the adjacent ones in a sustainable way. Through the monitoring of a selection of variables, the dissociation of the three main areas seen so far is evaluated: energy demand, economic growth and emissions [10] (Figure 3) that are homologous to the dimensions of sustainable development (environment, economy and society). To which we add the two new specific areas of energy sustainability: market regulation and social equity.

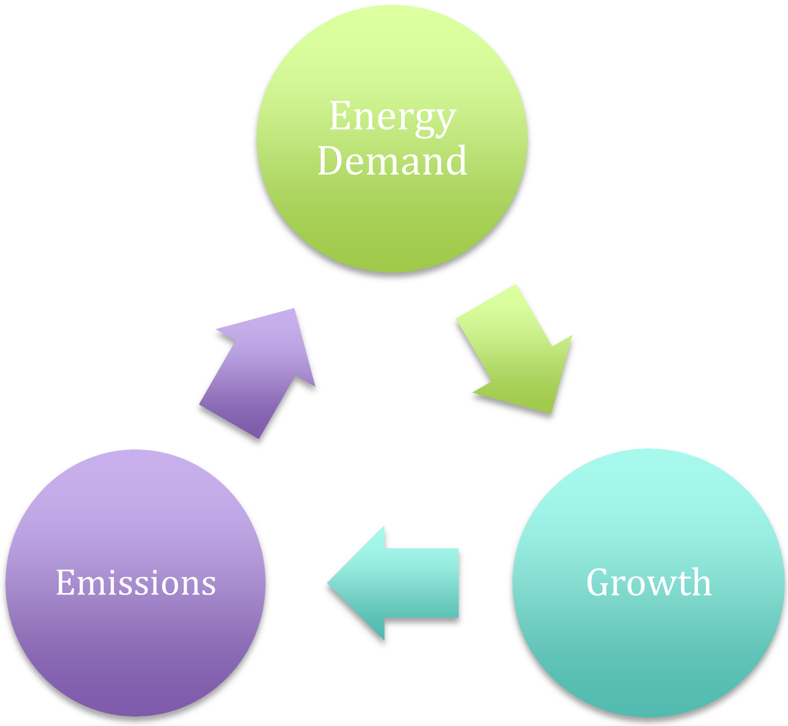

Figure 3. The three pillars of energy sustainability.

The theoretical concept in which validation is sustained is called dematerialization, in which the reduction of energy consumption will increase growth and should also lead to a reduction in the volume of waste and emissions generated. In short: it will be a source of sustainability to produce and therefore generate added value by reducing energy consumption, which must be accompanied by a reduction in the volume of waste and emissions generated: only then will there be sustainability.

For the validation of the model, the variables have been monitored for a decade, relative to the five main areas described in the previous point, seeking the dissociation of variables (emissions-growth-demand). By studying the correlations of the variables within each of the five areas and analyzing whether their relationship is sustainable or not, the following qualitative results have been obtained (Table 3).

Sustainability	Sustainable Economic Growth	Reliability of supply and energy demand			Markets and Regulation	Emissions		Social equity	Result
	EIE-GDP	FED-PEC	FED-GDP	GDP-PEC	TI-EIE	GDP_{PC}-EI	GDP-E	SPI_C-GINI	
UK	YES	YES	NO	YES	YES	YES	YES	NO	
Francia	YES	NO	YES	YES	NO	YES	YES	NO	
Italia	NO	NO	YES	YES	YES	NO	YES	NO	
Alemania	YES	YES	NO	YES	NO	YES	NO	YES	
España	NO	NO	NO	NO	NO	NO	NO	YES	

Table 3. Summary of the study of sustainable behaviors based on the dissociation of variables.

Variables related to the Energy Intensity of the Economy (EIE), Foreign Energy Dependence (FED), Primary Energy Consumption (PEC), Technical Intensity of the Energy System (TI), Gross Domestic Product (GDP), Gross Domestic Product per capita (GDPpc) have been used, GHG Emissions (EI), GHG Emission Intensity (EI) and Social Progress Index (SPI) and Inequality (GINI) for each nation, bi-dimensionally correlated and by analyzing whether their evolution corresponded to a sustainable or non-sustainable behavior. The results show that the United Kingdom is the most sustainable country, followed by France and Italy. At the tail of this classification would be Germany and Spain.

Finally, referring to factors determining sustainability in the productive sectors and more specifically in the industrial sector, taking into account that the three main areas of energy sustainability that will be critical are: pollution, growth and energy demand, correlations can be established between the following variables in this sector: Gross Value Added vs. Final Energy Consumption, Emission Intensity vs. Final Energy Consumption, and finally and given that the electric vector represents an important energy flow: Final Electricity Consumption vs. Gross Value Added. Analyzing this last correlation, the countries that show sustainability are France and the United Kingdom [6].

7. CONCLUSIONS

This paper presents a model of suitable indicators based on the concept of Energy Sustainability in five main areas on which to perform the disaggregation of indicators. These five main areas are: reliability of supply, regulation of demand and markets, access to energy in equity, growth momentum and sustainable economic development, as well as respect for the environment and diversity.

A model characterized by the General Index of Energy Sustainability (GIES) composed of the general indicators defined for each of the five representative areas of energy sustainability is proposed. The lower the value of the GIES, the greater the sustainability obtained.

The validation of the model has been carried out by applying the theory of dematerialization through a correlation analysis to justify the dissociation of the growth-emissions-demand pillars qualitatively. There is no other model which provides a validation of the same using the theory of dematerialization.

The GIES allows to overcome the interpretation of the indicators independently, since it takes into account the multiple areas of energy sustainability. For example, the Energy Intensity of the Economy (EIE), is not a stand-alone indicator that can demonstrate whether or not sustainable behavior is performed by countries and their activity; since a positive evolution of this indicator may not necessarily mean an improvement in the country's energy sustainability conditions, but rather a simple reduction in energy demand in a particular scenario, for example, of economic crisis.

Furthermore, the different economic, energy, territorial and social situations of the different countries mean that the model must be adapted, that is, not all variables will be the most suitable for analyzing the energy situation in the different nations. The model also raises the concept of local sustainability, selecting comparable nations as those that have their situation parameters within limits of certain clusters of variables.

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SUPPLEMENTARY MATERIAL

The Brundtlan Report presented at the United Nations World Commission on Environment and Development in 1987 reflects the definition of the concept of "sustainable development" and explains that decisions can be grouped into three main areas: firstly in the field of education and the culture (social dimension) that fosters adequate and healthy habits in the use of energy from schools and that includes dissemination actions towards citizens, including training and education activities in more disadvantaged social environments to educate in healthy habits from the point of view of energy consumption and guarantee access to it in conditions of equity. Secondly, in the field of energy efficiency and use of clean technologies (environmental dimension), since in the EU there are great challenges related to the decarbonization of the energy mix and measures to reduce energy demand [1] and [2]. Thirdly, the global problem (economic dimension) of the connection between economic, energy and environmental interests still persists, with the risk that economies with intensive energy consumption face unequal competition [3] in the face of future polarization of energy demand by emerging countries that will lead to an increase in world energy consumption by a third between 2035 and 2040 [4] and [5].

On the other hand, the use of the weak sustainability paradigm [6] is the only one that allows the substitution of natural capital by the other two (social and economic) that takes into account the transversal force of technology [7], which allows to extend the limits of natural capital and make it unlimited while substitutable, the latter occurring through the strong paradigm of sustainable development, which cannot be reasoned since it entails short-lived and limited natural capital.

Also, given the existence of very differentiated geopolitical aspects on the continents such as very different degrees of environmental commitments or the different level of protection of human rights and, of course, the different levels of wealth and access to technology and the existing forms of energy, this paper has established the European Union as a continent of reference for the analysis. The Millennium Development Goals report [8] already clearly expresses the link between the progress of society and energy, and not only that, but also proposes investment needs to achieve the objectives estimated at USD 15 per capita for the years 2006-2015. According to the report "Sustainable Energy for All 2015 - Progress Toward Sustainable Energy" [9], global investment needs will increase fivefold in the next few years: from 9 billion USD in 2012 to 45 USD in 2030.

There are other models of indicators, proposed by different organizations for the monitoring of data at an international level [10], [11], [12]. Many of them are complementary and serve as a great help for energy decision making. There are also independent indicators of the energy performance of systems such as the Energy Intensity of the Economy [13], [14], or the Energy Return on Energy Invested [15] and [16], or even more sectoral indicators such as those concerning social poverty and its energy implications [17] that offer information for evaluating the energy performance of a system.

The determination of the variables will first question their suitability [18] to the different economic, energy, territorial and social situations of the different countries, that is, not all the variables will be the most suitable to perform an analysis of the energy situation in the different nations taking into account the concept of local sustainability. For example, a region such as Western Europe, where there is a large dependence on energy from abroad and a very important contribution from the electricity sector in the final energy available, will need to evaluate variables that will have nothing to do with those necessary for the Central African region, whose electrical dependence is much lower. Somalia, a country in which agriculture accounts for 60.2% [19] of its GDP has a completely different energy situation from the United Kingdom whose agriculture accounts for about 1% [20] of the GDP.

In addition, large contrasts occur when electricity consumption ratios are handled: in Bangladesh the average consumption per person is 0.2 MWh, in India of 0.7 MWh, in Germany of 7 MWh, rising 13 MWh per person per year in the United States [21] and [22]. Therefore, the indicators for decision-making in developing countries must be significantly different from those of others with more advanced economies. At this point it is necessary to define the premise of the suitability of indicators: not all variables will be the most suitable for an analysis of the energy situation in different nations. Therefore, we should no longer talk so much about energy sustainability variables, but rather about clusters of sustainability variables that will be suitable for different nations.

The three most important features to be taken into account for the observation of the variables that allow determining indices are the following: first, a broad periodicity must be defined, which allows for an observation according to the nature of the variable. Second, to have updated, reliable and homogeneous information, which allows comparison between different countries by obtaining data with the same methodology. Thirdly, the data must have a sufficient level of disaggregation that allows observing behavioral patterns or patterns in the series that compose them. A few correlations obtained in the validation of the model are not conclusive because the series of data obtained have a very small final sample size. Therefore, larger series should be obtained to fully validate the model.

The reduction of energy consumption and therefore energy efficiency is a common objective to achieve energy sustainability and, ultimately, sustainable development. Therefore, all these aspects will be taken into account to define the global indicator. The model must analyze variables from different fields (social, economic, environmental, ...), in order to have a vision with sufficient diversity that considers all facets that have some energy implication in nations [23] and [24]. In addition, there is a theory of decoupling indicators of purely economic variables such as GDP as propounded by recognized international organizations [25] and [26].

To improve the suitability of indicators it is advisable to eliminate the variable of the composition of the different productive sectors by analyzing those countries with a similar income per capita, and with a similar specific weight of their economic sectors: the tertiary or services sector, the industrial sector and that of agriculture and livestock. In addition, this will result in more equity from the energy point of view other variables intrinsic to the situation of the productive sectors.

On the other hand, from the point of view of infrastructures, it is noteworthy that economies with a similar structure of the transport sector (evaluating indicators of freight transport activity or distance traveled per capita, or even CO2 emission intensity in this sector), will also facilitate standardization in the comparison of prices and energy consumption.

Theories of resource sustainability and dematerialization [27], [28], [29], [30], [31], [32] base their arguments on the Environmental Kuznets Curve (EKC) in that, from a certain level of income per capita, growth does not imply greater energy consumption.

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