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Vulnerability and Resilience: An Attempt to Theorize

Fiona Bénard *

PIMENT, 120 Av. Raymond Barre, 97430, Le Tampon, Reunion; E-Mail: fiona.benard@univ-reunion.fr

* **Correspondence:** Fiona Bénard; E-Mail: fiona.benard@univ-reunion.fr

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Abstract

In the context of resource depletion and global warming, the energy transition has become a necessity. To provide a basis for analysis and to support countries in this transition, it is necessary to better understand this transition. The creation of a good measurement tool could help. This paper proposes a measure of national resilience through an analogy to kinetic energy. Preliminary results show that some countries have strong potential for resilience in the energy transition. Inequalities exist and still exist in terms of accessibility to energy but the energy transition could generate an interesting catch-up for the most vulnerable countries. Finally, the impulse of the transition seems to be easier than the completion of this transition.

Keywords

Energy transition; resilience measure; kinetic energy; principal component analysis

1. Introduction

Analyzing the vulnerability of a territory consists in identifying its weaknesses and its exposure to a hazard. Over the years, researchers and engineers have been able to accurately calculate and predict the magnitudes of a hazard and propose appropriate strategies to defend society [1]. For example, for flood hazards, the defense strategy has been the construction of dikes and dams. It is, therefore, a question of finding a way to oppose the hazard. But this implies predicting the intensity of the disaster as precisely as possible to size the defense structures, which in this case are dikes and dams. However, the hazards are unpredictable, and so are their impact. In terms of risk management, this approach is, therefore, rapidly reaching its limits. It is, hence, interesting to refocus on impact and society, more specifically on society's ability to cope with impacts. In other words, it is rather a strategy based on resilience.

The concept of resilience is complex and refers to the notion of balance in a system, as applied to physics, ecology or social sciences. This state of equilibrium can be simple or plural. In any case, resilience refers to the ability of a system to bounce back to its equilibrium state after a disruption [1]. This synthetic definition is derived from the physical, social and ecological sciences. Ecological sciences add an important element of definition: it is necessary for the system to bounce back to reach its level of stability again, but without changing its structure [2]. This element of precision cannot be applied to define a territory's resilience to an energy shock. Indeed, it can be considered that there are several equilibrium states in an economic and societal system where structure changes can be considered. The structure of the system can be considered to evolve and follow a dynamic trajectory over time. At each point of its trajectory, a photograph can be taken to describe its structure. This photograph corresponds to a description of the structure of the system at a given time. This description of the state characteristics describing the system shows its strengths and weaknesses. In short, it can be equated with vulnerability.

For a clean energy at an affordable cost in the context of depletion of resources, global warming and growing inequalities in the world, the United Nations have set the following Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy[1]. Progress on this objective is analyzed through the RISE[2] indicator [3]. This composite indicator itself is composed of the following sub-indicators: Renewable energy, Energy efficiency, Clean Cooking and Electricity Access. On a scale of 1 to 100, it gives a good indication of the level of energy infrastructure, progress and policies of a country and compares it to other countries. The energy transition is a reality that no country can ignore. In the context of global warming, all societies will have to adapt and initiate a change even though they have become increasingly dependent on fossil fuels. These energies are inexpensive, but price volatility, rising global demand and the need for a secure supply are all obstacles and threats that weigh on countries [4]. Energy is essential to all human activities and has thus become a central element of a country's economy over the last two centuries. Energy is in a way the blood that runs through the veins of a country's economy [5]. It is a determining element that can promote a state of economic prosperity or economic crisis. It is the massive use of all forms of energy, especially oil, that has enabled developed countries to grow at a sustained and unprecedented pace [6]. The issue of energy is therefore central and the energy

[1] https://www.un.org/sustainabledevelopment/.

[2] Regulatory Indicators for Sustainable Energy.

transition is becoming a necessity today, as evidenced by the oil shocks, climate disasters and the increasing scarcity of resources, which will force the world to change its energy paradigm.

This work proposes an analysis of the resilience of countries in the face of the energy transition through the proposal of a measurement tool. The concept of energy vulnerability of territories and their resilience remain relatively unknown today, and no measurement method can accurately represent the concept. The multidimensionality of the concept and the great diversity of situations in the territories make measurement difficult, especially through a single indicator. While the need to better understand resilience in the management of global warming-related disasters is becoming urgent, the lack of a consensual measurement tool is becoming an impediment to progress on the ground [7]. Resilience is nevertheless a major concept in the field of development aid [8]. The search for resilience is an integrated approach, covering both the anticipation of a crisis, its management in case of occurrence and also the management of the post-crisis situation [9]. The stakes of resilience for territories are therefore high, as is the need to measure it. This article is part of this objective: the measurement of resilience, and more specifically, energy resilience. This work links vulnerability and energy resilience and proposes a two-part measurement method: the first step is a multivariate analysis for the creation of a vulnerability indicator, then an analogy between resilience and kinetic energy in the second step. The originality of the article lies in the second point, kinetic energy is a fundamental notion of physics that is still little known in social and geographical sciences. The creation of a single indicator of measurement allows easy comparison between different countries of different types, wealth, economic and social structures, and political regimes. The prism of analysis is the energy transition.

The rest of the paper is organized into three parts. The material and method section first conceptualizes the notion of energy vulnerability and resilience and then proposes a two-part calculation method: the calculation of a synthetic vulnerability indicator, followed by an analogy to kinetic energy to represent resilience. The results are then presented in the order previously proposed: an analysis of the vulnerability indicator and then an analysis of the resilience of the countries considered in the analysis. Finally, all the results and the method are discussed in the last part before the conclusion.

2. Materials and Methods

2.1 Theorizing Vulnerability and Resilience

There are numerous definitions of vulnerability and the disciplines that use them are equally important [10, 11]. There are several definitions, but research on vulnerability has led to notions of risks and hazards. For example, in geography, vulnerability maps offer spatial distributions of issues that are directly exposed to a hazard [12]. These issues, which are directly related to humans and their habitat, clearly show the relationship between society and the environment at various spatial and temporal scales [13]. The analysis of vulnerability also always involves the emergence of the notion of shock, disaster and damage. Disaster is a sign of vulnerability that disrupts the normal functioning of a system (society) by causing an emergency and a bifurcation towards a new system [14]. Society is then characterized by its ability to respond to this disruptive shock, which takes the form of a threshold of damage that society can support. The notions of resistance and resilience are then intrinsically linked to the notion of vulnerability. Analyzing vulnerability means looking at the ability of society to absorb a shock. It is the ability to resist such shock and then manage its consequences. The objective is to ultimately find a function close to its initial state or simply a new stabilize state which is called resilience [12, 13].

Around the concept of vulnerability, there are several other concepts of shocks, catastrophes and damages, as well as notions of resistance and resilience. Figure 1 schematizes this concept.

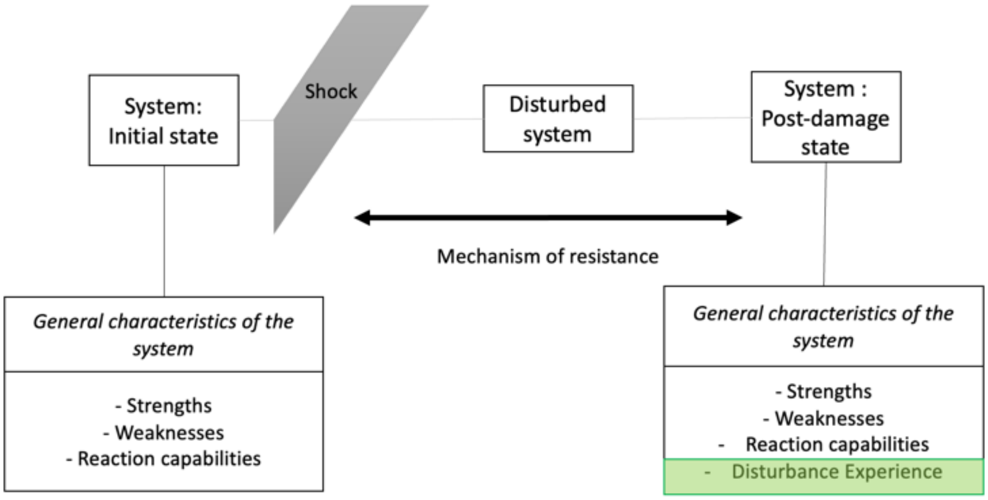

Figure 1 Vulnerability schematic of a system.

A system is defined by general characteristics that can be either strong or weak elements. These systems' definition elements/parameters are structural and functional elements that are participated in the characterization of the system health and their stability over time is an indicator of good health. All this makes it possible to define the reaction capacity of the system. The emergence of a shock disrupts the system and causes a succession of disruptive elements that will activate the resistance mechanism of the system. Once the shock has been absorbed, the system will return to a stable state that may not be at the same level as the initial state. When the system is able to return to a stable state, the system can be considered resilient. When the system fails to regain stability, or when it disappears, the system is non-resilient. In a post-damage state, one may consider that the system has learned the sudden shock and will display its disturbance experience as a new characteristic.

Vulnerability is a concept that can be related to the hard sciences and humanities. We can therefore consider that vulnerability approaches can be separated into two categories [15]. The first approach would be more sociological in nature: vulnerability is understood as a propensity for damage. The second approach would be technical in nature, where vulnerability would rather be a measure of damage [14, 16].

When characterizing a territory such as a country, we can draw from economic vulnerability to distinguish two other types of vulnerability [17]:

- the structural vulnerability: it is a vulnerability specific to the state of the system and inherent to its physical properties.
- the political vulnerability: it depends on a non-permanent and evolving state in the wake of the country's political events.

The structural vulnerability is quite clear since it is about the physical vulnerability and the material vulnerability, which is the easiest one to identify. Its analysis involves analyzing the impacts, characteristics (nature, intensity, frequency) of the hazard or the degree of exposure [18]. Applied to the territory, the structural vulnerability will concern the areas directly affected by the hazard. The functional vulnerability of the territory will rather concern areas linked to the impacted territory that will suffer indirect consequences of the damage that occurred [18]. There are thus many scale effects of vulnerability and the meaning of vulnerability can change depending on whether an individual, a family, an infrastructure, a network or an entire territory is studied [14]. The literature has thus introduced the notion of territorial vulnerability [18-21], where territorial vulnerability considers the territory as a complex system with interdependent elements. Then, there are elements in the system (i.e. the territory) that are capable of generating and spreading their vulnerability to an entire territory, and this diffusion indirectly leads to consequences that compromise the overall functioning of the system, or even its development. Therefore, the challenge of analyzing territorial vulnerability involves identifying fragile/vulnerable areas that, when affected, can disrupt other areas of the territory [19].

Resilience is a concept intrinsically linked to vulnerability and the two concepts are often considered opposites [22, 23], one with rather positive aspects and the other with negative aspects. The term resilience is positive and it originates from "*resilio*", a Latin word that means to rebound. It is, therefore, a question of bouncing back after having suffered a shock. It is the capacity of a system to absorb a shock and to recover its initial state thereafter [1]. Like vulnerability, the definitions and the measurements of resilience are also numerous [1, 24]. Resilience measurement can be studied by considering the maximum amplitude of the hazard that the system can support (and continue to exist). However, this maximum amplitude is difficult to evaluate.

To complete the definition and measurement, in the sense of maintaining the functions, resilience can be equated with persistence [2]. Resilience is then the inverse of a return time. The return time is the time it takes for a system to find an equilibrium state after disruption [1], depending on the intensity of the shock. Figure 2 schematizes the concept of resilience: the good health of a system is expressed as a function of time.

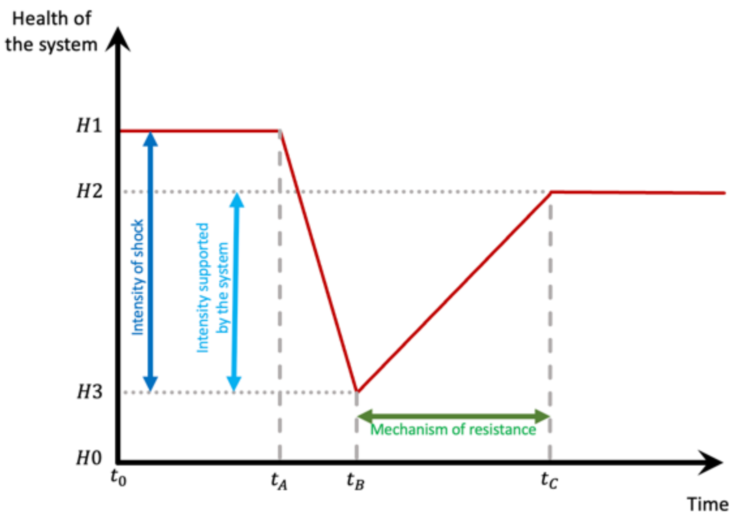

Figure 2 The concept of resilience.

The system is stable over time until the intervention of a disaster in t_A which disturbs the system. From t_A to t_B, the system is impacted. From t_B to t_C, the system activates its resistance mechanism to reach a new stable state at t_C, which is a sign of its resilience. Resiliency is expressed through two elements:

- $\tau_1 = t_B - t_A$, the reaction time of the system.
- $\tau_2 = t_C - t_B$, the duration of the reaction, the time needed to reach a new stabilized state (H2). $\tau_1 + \tau_2$ is the return time.

However, resiliency is also a shock intensity issue that can be absorbed by the system. The intensity of the shock can be formulated by $\iota = H1 - H3$. The intensity supported by the system is $\iota_s = H2 - H3$. ι_s characterizes the vulnerability of the system.

Resilience can then be summarized as the existence of a shock that triggers a response mechanism in a subject that was previously in a steady state and the subject is qualified as resilient if it regains a state of stability. Measuring resilience would then amount to measuring the strength of the subject during its response movement (from t_A to t_C), so that analogy to kinetic energy could then be made. Kinetic energy is indeed the energy that a body possesses because of its motion, which means that this body goes from state A to state B by a moment of movement, and this moment of movement generates in it the acquisition of an experience. Figure 1 and Figure 2 illustrate well this passage from a state of stability to another state of stability by a period of disturbance. This perturbation experience increases the mass of the body considered [25].

2.2 A Multivariate Analysis: Principal Component Analysis

To have a multidimensional synthetic indicator, we use Principal Component Analysis (PCA). PCA is a method for exploring and visualizing quantitative data. The analysis of the PCA is done through three main results: eigenvalues, which allow determining the most relevant principal components to be analyzed (according to the explained variance rate); correlation circles, which allow to analyze variables and to identify which ones are useful for the analysis of principal components (the size of the vectors and the value of Cos^2 are used); and graphs of individuals. Performing a hierarchical ascending classification on the PCA results then allows us to visualize groups of countries (clusters), thus leading to an easier interpretation of the vulnerability results.

The interest of PCA is twofold: on the one hand, it has the advantage of being able to synthesize the input data through the creation of new variables, the principal components, to maximize the variance of the data; on the other hand, it allows to identify the impact of each row (individuals) and column (variables) element in a data set to highlight all the links between individuals, variables and principal components. On this second aspect, it is then possible to build a synthetic indicator by considering:

$$I = \frac{\sum_{i=1}^{n} \lambda_i Dim_i}{\sum_{i=1}^{n} \lambda_i}$$

With λ_i is the eigenvalue associated with dimension i and $\mathrm{Dim_i}$ is the principal component i.

Then we have:

$$Dim_i = f(v_j, \dots, v_n) = \sum_{j}^{n} \alpha_j v_j$$

With v_j is the input variable v_j and α_j the contribution of the variable v_j to the construction of the dimension i.

The selected v_j data are all from the World Bank[3]. We have: GDP per capita (current US$); Population; Imports of goods and services; Exports of goods and services; GDP growth (annual %); Urban population; Industry, value added (% of GDP); Agriculture, value added (% of GDP); Trade in goods (% of GDP); and Trade in services (% of GDP).

Data for 108 countries (see Table 1) were collected for 2019.

Table 1 List of countries.

Country	Code	Country	Code	Country	Code
Albania	ALB	Guinea	GIN	Nigeria	NGA
Argentina	ARG	Greece	GRC	Nicaragua	NIC
Armenia	ARM	Guatemala	GTM	Netherlands	NLD
Australia	AUS	Honduras	HND	Nepal	NPL
Austria	AUT	Croatia	HRV	Oman	OMN
Azerbaijan	AZE	Haiti	HTI	Pakistan	PAK
Belgium	BEL	Hungary	HUN	Panama	PAN
Benin	BEN	Indonesia	IDN	Peru	PER
Burkina Faso	BFA	India	IND	Philippines	PHL
Bangladesh	BGD	Ireland	IRL	Poland	POL
Bulgaria	BGR	Israel	ISR	Portugal	PRT
Bosnia-Herzegovina	BIH	Italy	ITA	Paraguay	PRY
Byelorussia	BLR	Jamaica	JAM	Qatar	QAT
Bolivia	BOL	Jordan	JOR	Romania	ROU
Brazil	BRA	Japan	JPN	Rwanda	RWA
Switzerland	CHE	Kazakhstan	KAZ	Sudan	SDN
Chili	CHL	Kenya	KEN	Singapore	SGP
China	CHN	Kyrgyz Republic	KGZ	Sierra Leone	SLE
Ivory Coast	CIV	Cambodia	KHM	El Salvador	SLV
Cameroon	CMR	Korea, republic of	KOR	Serbia	SRB
Congo, Democratic Republic of	COD	Kuwait	KWT	Slovak Republic	SVK
Colombia	COL	Lebanon	LBN	Sweden	SWE
Costa Rica	CRI	Sri Lanka	LKA	Togo	TGO
Czech Republic	CZE	Morocco	MAR	Thailand	THA
Germany	DEU	Madagascar	MDG	Tajikistan	TJK
Denmark	DNK	Maldives	MDV	Turkey	TUR
Dominican Republic	DOM	Mexico	MEX	Tanzania	TZA

[3] https://www.worldbank.org/en/home.

Algeria	DZA	North Macedonia	MKD	Uganda	UGA
Equator	ECU	Mali	MLI	Ukraine	UKR
Egypt	EGY	Myanmar	MMR	Uruguay	URY
Spain	ESP	Montenegro	MNE	United States of America	USA
Ethiopia	ETH	Mongolia	MNG	Uzbekistan	UZB
Finland	FIN	Mozambique	MOZ	Vietnam	VNM
France	FRA	Mauritania	MRT	South Africa	ZAF
United Kingdom	GBR	Malaysia	MYS	Zambia	ZMB
Ghana	GHA	Niger	NER	Zimbabwe	ZWE

2.3 Resilience of Territories: An Analogy to Kinetic Energy

In short, kinetic energy can be defined as the energy that a body possesses because of its motion. The notion of motion is, therefore, essential and it implies a state of rest before the start of the motion. Another way to present this is that the kinetic energy of a body is equal to the work required to move the body from rest to motion. The body has two states: a stationary state and a state of motion caused by forces exerted on it. By assimilating the forces exerted to the notion of shock or disaster presented in Figure 1 and Figure 2, one could then deduce that the kinetic energy could actually be assimilated to the resilience of the system.

Considering the following equation for the kinetic energy:

$$Ek = \frac{1}{2}mv^2$$

With E_k is the kinetic energy, m is the mass of the moving body in kilograms (kg) and v is the speed of the moving body in m/s. Two parameters are essential to the calculation: the weight of the body and the speed of its movement are taken into account. One characterizes a state and describes it, and the other translates a motion, an evolution.

We can deduce the formula for calculating the resiliency R:

$$R = \frac{1}{2}I\rho^2$$

With I is the synthetic indicator calculated with the PCA, thus representing the weight of the system studied; ρ, is the movement indicator which will designate here the growth rate of a key indicator, allowing the analysis of a country's energy policy: RISE. The value of this indicator was collected in 2010 and 2019 and a growth rate was calculated for each country.

As with the PCA, data were collected for in 2010 (the earliest year of data collection) and 2019 (the most recent year available) in the same 108 countries. ρ representing a movement, we calculated a growth rate as follows:

$$\rho = \frac{(RISE_{2019} - RISE_{2010})}{RISE_{2010}}$$

3. Results

3.1 PCA and Synthesis Indicator I

The first element of analysis and interpretation of a PCA is the eigenvalues. Indeed, these values will indicate the number of useful principal components to be retained in the analysis and the associated explained variance. Using the Kaiser criterion [26], we selected the first four principal components (bolded in Table 2) that were able to explain 86.79% of the variance of our data.

Table 2 Eigenvalues.

	Eigenvalue (λ)	% of the variance	Cumulative % of the variance
comp 1	**4.1821**	41.82	**41.82**
comp 2	**1.9302**	19.30	**61.12**
comp 3	**1.5374**	15.37	**76.50**
comp 4	**1.0296**	10.30	**86.79**
comp 5	0.5961	5.96	92.75
comp 6	0.3731	3.73	96.49
comp 7	0.2659	2.66	99.14
comp 8	0.0469	0.47	99.61
comp 9	0.0387	0.39	100.00
comp 10	0.0000	0.00	100.00

The analysis of the correlation circles of the first 4 components allows us to understand the positioning of the variables on these components, as well as the relationships between them. Figure 3 provides information on these variables. First, dimension 1 is mainly linked to internal and external trade variables: dynamic countries on the variables of production of goods, services, exports and imports are positioned on the right side of the graph. This includes countries such as Ireland (IRL) and Singapore (SGP) (Figure 4a).

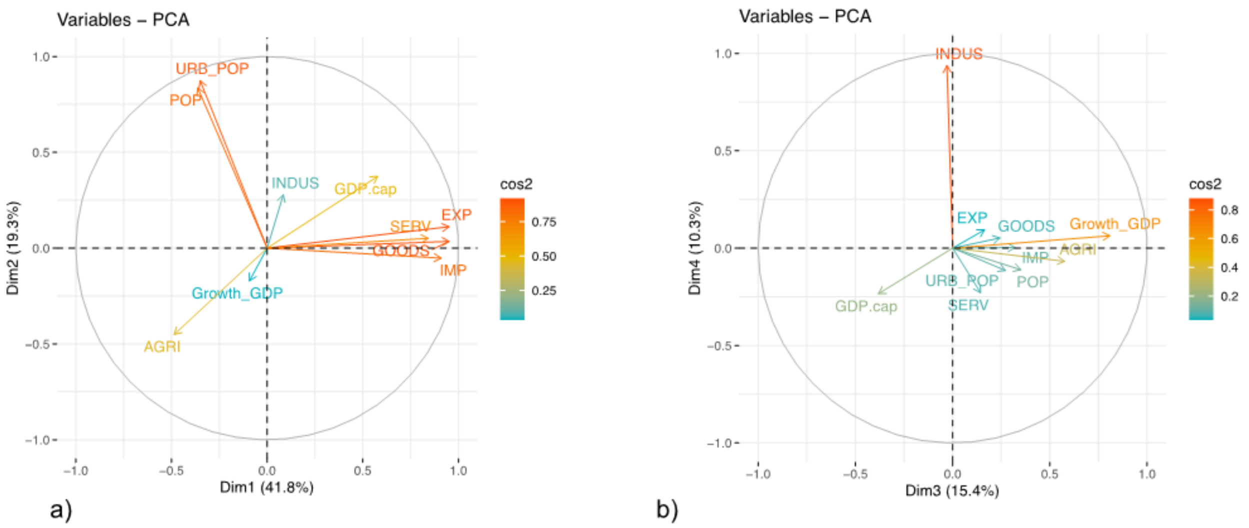

Figure 3 Correlation circles. *3a) Correlation circles of dimensions 1 and 2; 3b) Correlation circles of dimensions 3 and 4*.

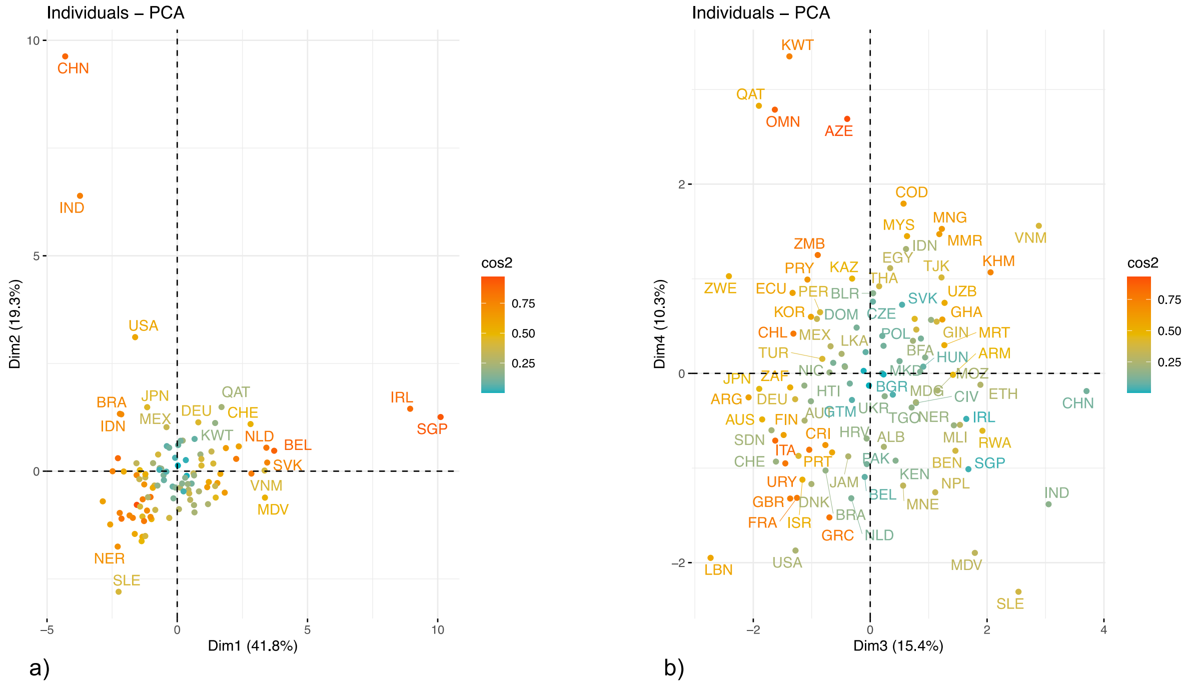

Figure 4 Individuals - PCA Results. *4a) Representation of individuals on dimensions 1 and 2; 4b) Representation of individuals on dimensions 3 and 4*.

Dimension 2 is related to the population and urban population variables (Figure 3a). Thus, countries with large populations, especially urban populations, are located at the top of the graph. India (IND), China (CHN) and the United States (USA) meet this criterion (Figure 4a). The GDP growth rate and the percentage of the agricultural sector in GDP are related to dimension 3. Thus, in Figure 4b, countries with a high share of agriculture in GDP and a high GDP growth rate are located on the right (China (CHN), India (IND), Vietnam (VNM)), while countries with negative growth and a low share of agriculture are located on the left (Lebanon (LBN), Japan (JPN), Zimbabwe (ZWE)). Finally, dimension 4 is essentially linked to the industry variable with countries with a high share of industry in the economy located at the top of Figure 4b (Kuwait (KWT), Qatar (QAT), Oman (OMN)) and, conversely, countries with a low share of industry in GDP (Sierra Leone (SLE), Lebanon (LBN), Maldives (MDV)) located at the bottom.

Clustering reveals 5 groups of countries (Figure 5). Cluster 1 (red) is composed of two countries: China (CHN) and India (IND). These two countries are characterized by a high population, especially in urban areas, a large share of agriculture in the GDP and a strong economic growth rate. Cluster 5 (orange), also composed of two countries (Ireland (IRL) and Singapore (SGP)), is essentially characterized by significant trade. Clusters 2 (blue, 29 countries), 3 (green, 39 countries) and 4 (purple, 36 countries) show average values in dimensions 1 and 2. Cluster 4, however, is distinguished by higher values on the trade variables (dimension 1). Cluster 3 has high values on the industry variable (dimension 4) and population (dimension 2). Cluster 3 also has a lower economic growth rate than Clusters 2 and 4. In addition, Cluster 2 consists mainly of poor and developing countries.

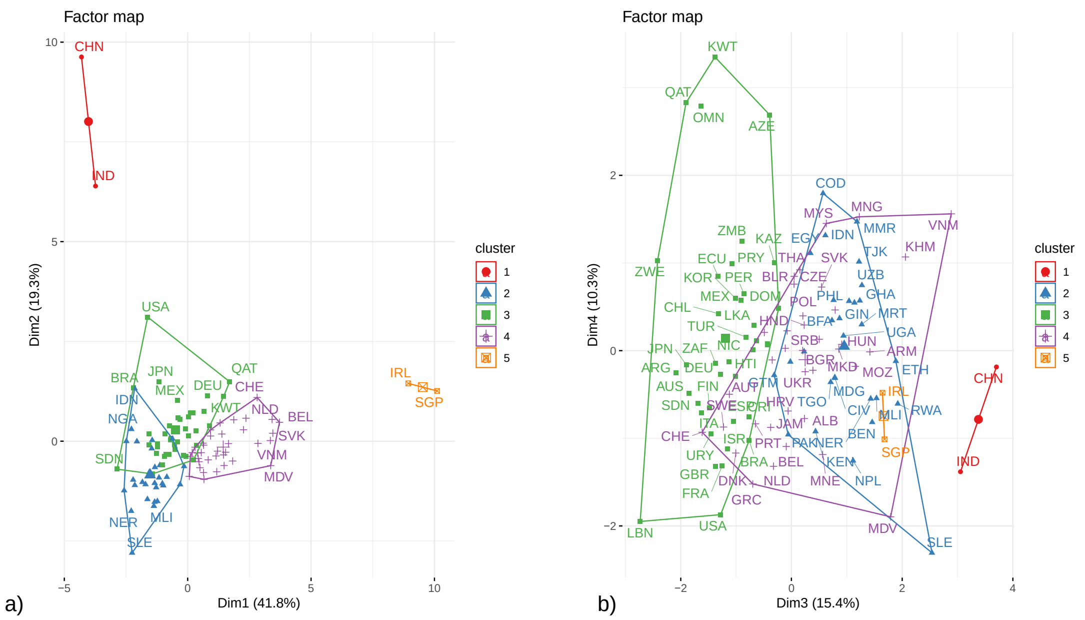

Figure 5 Factor map - Hierarchical clustering results of principal components.

The results of the calculation of the synthetic indicator are presented in Figure 6. The indicator positions the clusters as follows, from lowest to highest values: Cluster 1, Cluster 3, Cluster 2, Cluster 4 and Cluster 5. The indicator, with the chosen variables, must be able to represent the weight of a country's economy and the extent of its needs (especially through the population variables). We can then propose the following interpretation of the indicator: a negative result indicates an important weight of the population, which means that there is a particular tension in this element (in terms of economic, food, employment, activity and infrastructure); a positive result indicates a less important weight of the population, but the economy is based on commercial exchanges with weaker agriculture and industries.

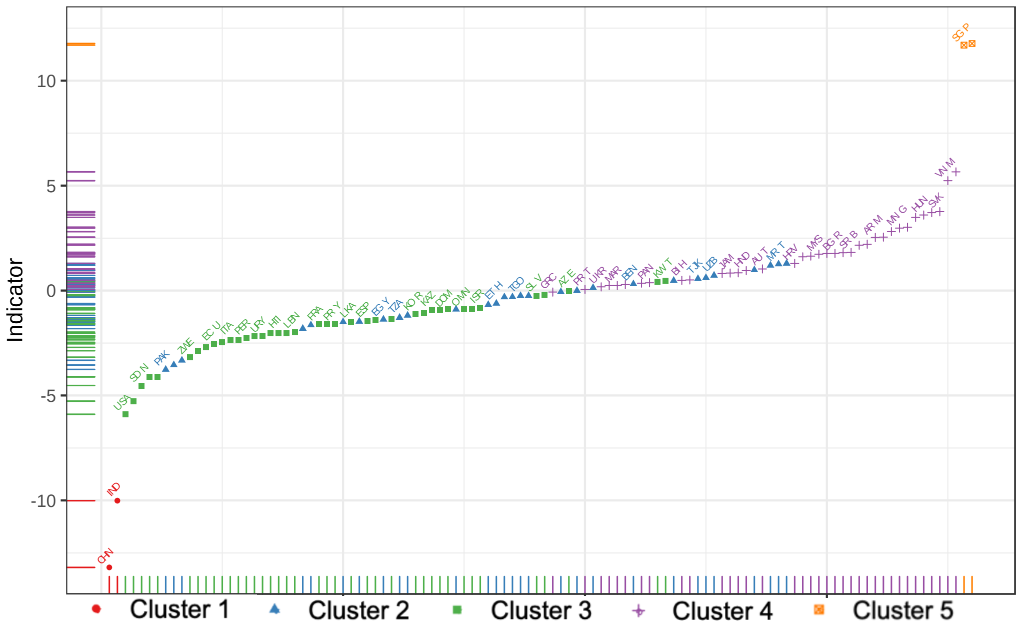

Figure 6 Synthesis Indicator.

3.2 RISE Score: An Indication of Political Dynamism in the Field of Energy

Of the same 108 countries considered in the PCA, we studied the RISE Score to establish an analysis of the political dynamism in the energy transition. The RISE Score for 2010 and 2019 have been considered and a growth rate has been calculated. To improve readability, we divide the countries into two groups: those with a growth rate below 1 (Figure 7) and those with a growth rate above 1 (Figure 8). Therefore, we notice that the highest growth rates concern countries with very low RISE scores in 2010, such as Sierra Leone (SLE) or Guinea (GIN). In the end, these countries have the most room for maneuver in terms of political developments since the scores are already very low. In contrast, countries with high RISE scores such as Ireland (IRL) and Belgium (BEL) (58 and 57, respectively) have more "modest" growth rates of around 0.5% over the period (Figure 7).

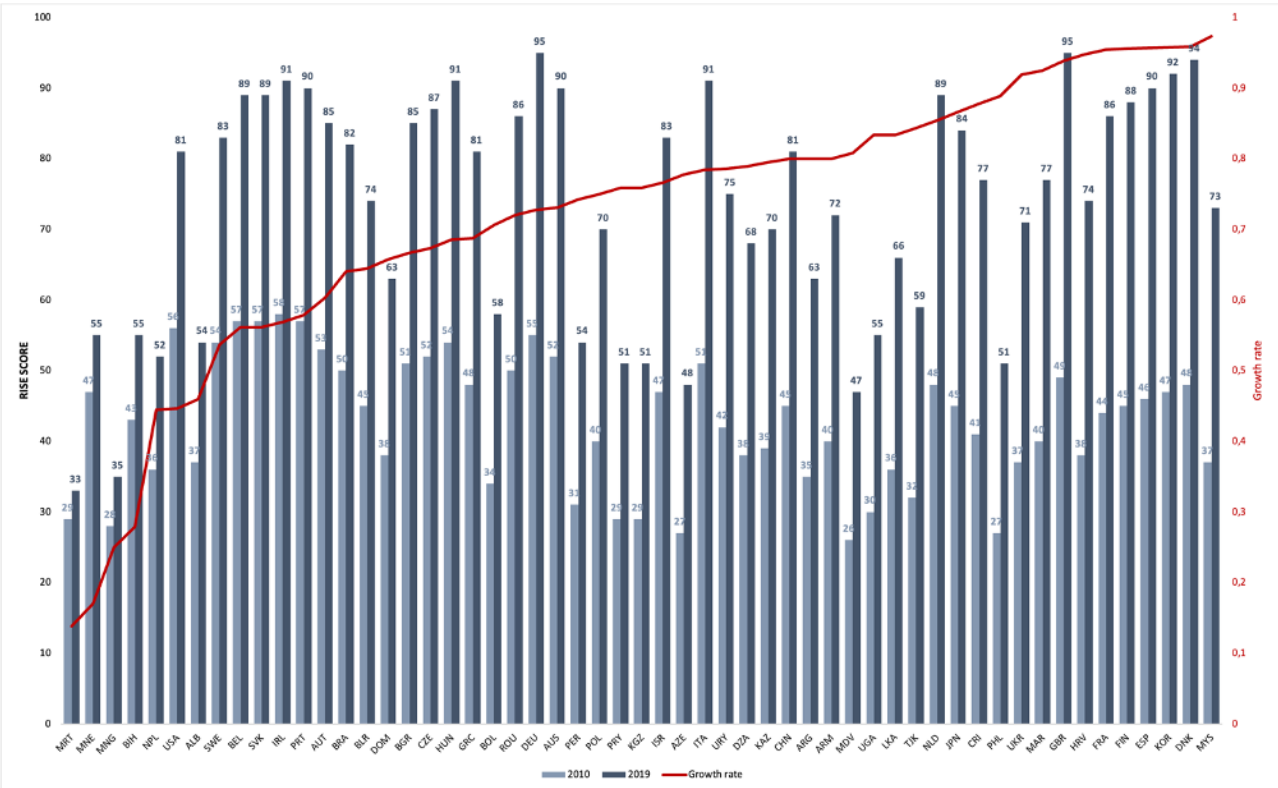

Figure 7 RISE score (a), Source: ESMAP[4].

[4] Energy Sector Management Assistance Program, http://RISE.esmap.org.

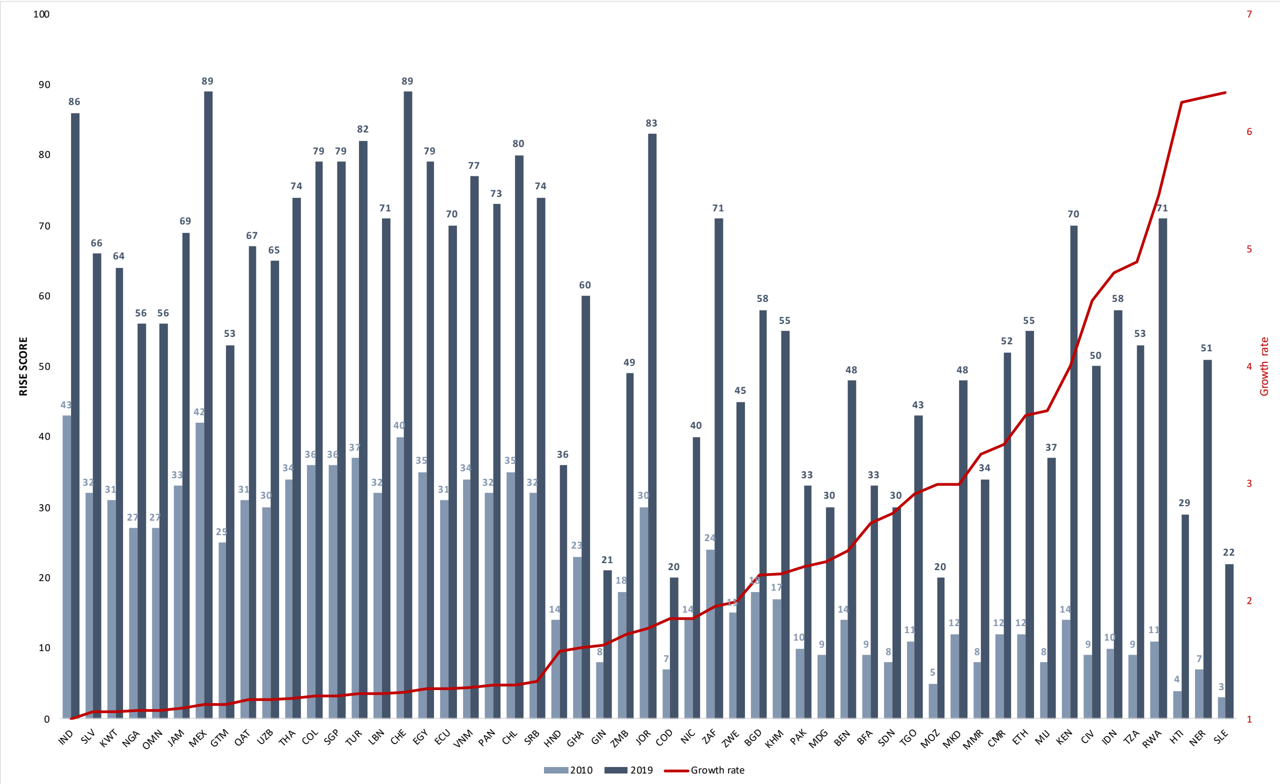

Figure 8 RISE score (b), Source: ESMAP.

3.3 Resilience of Territories: An Analogy to Kinetic Energy

The calculation of the kinetic energy implies the acquisition of two types of data: mass data, allowing to describe the state of the country; and velocity data, allowing to translate the impulse given by the shock and the capacity of the country to absorb it. In our study, the synthetic indicator calculated via the PCA is considered as mass (3.1) and the growth rate of the RISE indicator is used as velocity (3.2). To be able to use the PCA data I in the kinetic energy formula, the data has been normalized between 0 and 1 (the mass must not be negative). The results obtained are presented by visualizing the country clusters calculated previously (3.1) (Figure 9).

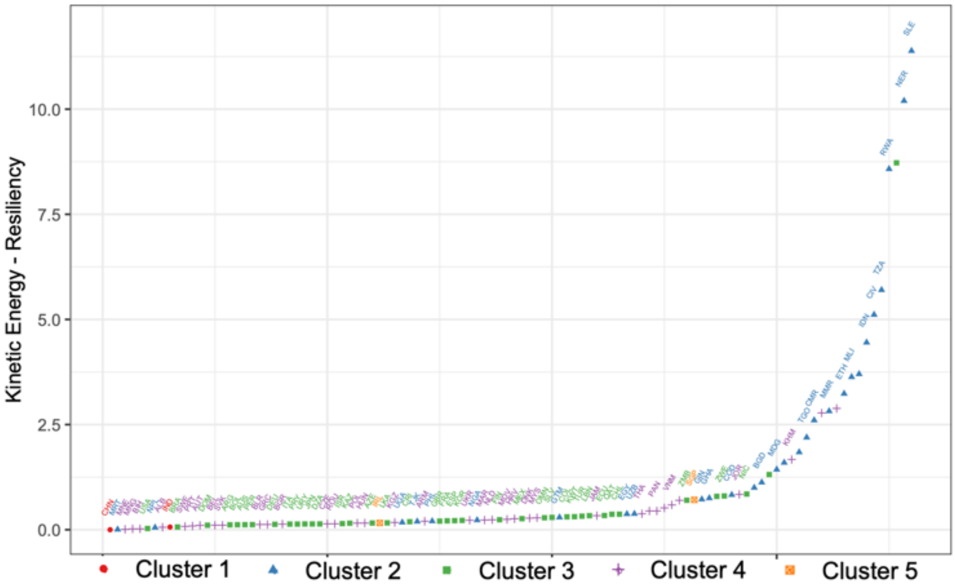

Figure 9 Final Results: an overview of the resilience by country.

The resilience of the countries studied ranges from 0 (China, CHN) to 11.39 (Sierra Leone, SLE), from less to more resilient, with a mean value of 1.03 and a standard deviation of 2.04. We observe a strong concentration of data around the average, which implies a certain homogeneity across countries. This is confirmed by the calculation of the kurtosis coefficient, which is equal to 11.97. To complete the analysis of the indicator, the skewness coefficient is positive (equal to 3.37) and thus indicates that the tail of the distribution curve is to the right of the mean. There is, therefore, a spread at the level of the strong values of the resilience indicator, but also a greater number of weak and average values. This finding allows us to assert two things: the high concentration of low-resilience countries in the sample studied and the strong disparities between countries with high and low resilience.

The analysis of cluster positioning provides some interesting insights. Indeed, cluster 1 shows low results implying that the size of the population especially the urban population, is an obstacle to the country's resilience. The size of the needs is a determining factor in the calculation of resilience. However, these countries have high values for energy policy dynamism (0.8 for China (CHN) (Figure 7) and 1 for India (IND) (Figure 8)). This reinforces the conclusion that the size of the population, particularly the urban population, is a break for resilience.

Clusters 3 and 4 have a high concentration around the average. With highly industrialized economies for cluster 3 and a strong focus on trade for cluster 4, these clusters show low to medium resilience scores. For these countries, the speed indicator is rather correct since the values are around 1, which implies a doubling of the RISE value over the period (e.g., France (FRA) from 44 to 46 with a growth rate of 0.95, Vietnam (VNM) from 34 to 77 with a growth rate of 1.26). The importance of the needs of these populous industrialized countries explains the rather low results on the resilience of the countries in cluster 3. For Cluster 4, the results, which are nevertheless higher than for Cluster 3, can be explained by the importance of trade.

While cluster 5 is scattered in the results of cluster 4, cluster 2 shows the best resilience results. For these predominantly poor and developing countries, political dynamism is key to the high value of resilience. With an average growth rate of around 268% for the countries in this cluster, policy developments around energy and progress have been significant over the period considered. These countries started with a much higher potential for progress than the other clusters since the average RISE score in 2010 was 16 compared to over 35 for all other clusters.

4. Discussion

Several conclusions can be drawn from the application of the kinetic energy principle to calculate resilience. The size of the needs, represented by the population, particularly in urban areas, is a determining factor in the final calculation. Indeed, this size will weigh on the weight of the country and therefore its capacity to become resilient. This is consistent with the definition of risk, which in geography corresponds to the concordance between the presence of issues and hazards in a circumscribed area. The stake is linked to man and his activity, without him the stake would not exist. An important population induces an increase in stakes and thus leads to an increase in risk, thus increasing the vulnerability of the country. While this conclusion must then be combined with an analysis of policy measures. Therefore, a country with important stakes (an important population), in order to face the energy transition, must engage more important means to ensure the transition. These political, human, technological and financial means, but above all, the absence or the impossibility of using them in certain countries, have the potential to cause and exacerbate major inequalities between countries.

Nevertheless, the countries starting with the lowest RISE score are the most resilient in our study. This fact is mainly explained by their greater possibility to progress in the RISE scale (which, as a reminder, evolves from 0 to 100). However, another hypothesis can be put forward: progress in energy policies and infrastructures is easier to be achieved when everything remains to be done, rather than in industrialized countries, with strong economies and large populations, for which the needs are more pressing. This hypothesis, if verified, is rather interesting in the analysis of territorial inequalities between countries. Indeed, access to energy, especially fossil fuels, has increased inequalities at the global level, and the energy issue is a determining factor in a country's development. The RISE indicator shows us that the efforts made by countries could allow poor countries to catch up with industrialized countries, thus reducing inequalities. The energy transition could, from this point of view, bring all countries to an equivalent level. However, this level of equivalence would be limited. It would be a matter of catching up to a certain point. The difficulties and obstacles that developed countries face today in completing their transition may be just as insurmountable, if not more so, for poor and developing countries.

Another interpretation could be drawn from this finding. The margins of progression could be more difficult to establish at the end of the scale than at the bottom. We thus observe an effect comparable to economic convergence, with countries at the bottom of the scale growing faster before reaching a stationarity level of convergence in most countries. This raises questions about the real possibility of initiating and achieving the energy transition. Many countries have embarked on this path since the oil shocks with initial measures to limit the impact of fossil fuels on their economies. However, fifty years later, this transition has still not been fully achieved by any country in the world. A reflection can then be initiated on the existence of different stages of the energy transition: it could be possible to identify sequential stages that countries should reach successively to achieve a completely successful energy transition. It would also be possible to consider different transition paths for different countries, or even groups of countries. Convergence club theories would then be applicable. As the results here show that it is easier to initiate the transition than to complete it, a reflection on the different types of support to be provided at the different stages or to the different “clubs” could also be undertaken.

The method used and the coefficients applied to mass and velocity may explain these findings and the high resilience scores of developing countries. Indeed, the kinetic energy formula involves squaring the velocity. In the principle of the analogy, this important weight given to velocity has therefore been retained. Thus, more weight is given to velocity than to mass. In the calculation made here, the RISE indicator is given a higher weight than the synthetic country state indicator. Since countries starting from the bottom have more room for maneuver, the resilience results can be strongly impacted. To correct this possible bias, the coefficient applied to speed could be lower. This would give more weight to the state characteristics of the countries (represented by indicator I). This approach could also take into account the efforts already made in terms of energy policy that will lead to the state characteristics of these countries at the time we study them. The interpretation of vulnerability and resilience will be broader and we will not be satisfied with a simple interpretation of the dynamics of the period considered (2010-2019), but with a comprehensive interpretation of the situation of each territory. We could also consider a different coefficient depending on the level of the convergence stage. This will make it possible to clearly establish the different difficulties between the different levels of convergence stages.

5. Conclusions

The work performed aimed to provide a possible measure of the resilience of countries to the energy transition through an analogy between the concept of resilience and kinetic energy. In the context of resource depletion and global warming, the energy transition has become a necessity. Many countries are committed to this path and many developments and innovations stem from this interest. Sustainable Development Goal 7 is a step in this direction. Ensuring access to reliable, sustainable, modern and affordable energy services for all is a global development challenge. To measure countries’ progress toward this goal, the United Nations has created the RISE indicator, which provides a clear picture of the energy situation of each country participating in the program. Supporting countries in their energy transition must involve two things: first, the ability to characterize the state of the country, its strengths and weaknesses; and second, the ability to measure the country's energy vulnerability or resilience in order to have a clear analysis of its capacities and realities. This work proposes to measure the resilience of countries in the face of the energy transition through an analogy with kinetic energy. Kinetic energy is the amount of energy that a body possesses because of its motion relative to a given reference frame. The analogy with the territory is then easy: a territory (in this case, a country) is a complex system, in constant evolution, composed of a multitude of interacting elements and subjected to a particular pressure that leads to important modifications: the energy transition. The energy transition is both a feature that affects the different state parameters (the given reference frame) and the variable translating the evolution, i.e. the movement.

The results obtained revealed several things. The first thing to note is that the resilience situations are more or less homogeneous, with a strong concentration of values around the average but with rather low resilience values. Secondly, it should be pointed out that, despite everything, there are existing disparities that countries with a greater margin of progress show themselves to be more dynamic and display high resilience values. Furthermore, the size of the population and the magnitude of the energy needs seem to be important constraints in the resilience of the country. Thus, the most populated countries have rather low resilience values. Finally, the progression grid seems to be more difficult at the end of the scale: countries scoring the highest values on the 2010 RISE indicator have average resilience scores, which implies that the magnitude of the efforts to be made is more important or more difficult at the top of the scale. This raises questions about the real possibility of a successful energy transition and highlights a similarity to economic convergence effects.

To take this work further, a different weighting between mass and velocity could be proposed. It would then be necessary to determine the weight to be applied to each parameter. Giving greater importance to mass could lead to a more comprehensive vision of the energy situation (vulnerability or resilience) of the countries by broadening the reading beyond the simple dynamics of evolution during the period considered (2010-2019). Finally, other concepts from physics could be used for the analysis of vulnerability and resilience. Kinetic energy has provided a good field of study but elastic potential energy could also be applied. The work could also be pursued by incorporating energy variables into the state characteristics. The premise here is to consider energy as an underlying, invisible, de facto integrated element in each economic sector used to calculate the state/mass indicator (I). By continuing the work, we could consider that energy is a factor as a factor in itself, which enters into the calculation of mass, making it possible to give even more importance to this central element of our contemporary societies.

Abbreviations

RISE	Regulatory Indicators for Sustainable Energy
PCA	Principal component Analysis
Cos^2	Cosine Squared
GDP	Gross Domestic Product

Author Contributions

The author did all the research work of this study.

Competing Interests

The authors have declared that no competing interests exist.

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