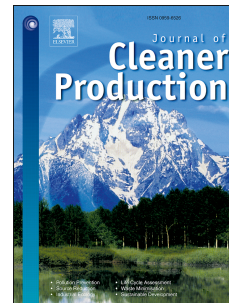


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Energy vulnerability around the world:

The Global Energy Vulnerability Index (GEVI)¹

Andrea Gatto²

Francesco Busato³

Abstract

Vulnerability has garnered an increasing attention from academia, international community and industry. Nonetheless, formal definition, mainstreaming, and measurement of vulnerability are still flawed in the economic literature. Energy vulnerability, intended as the exposure of an energy system to adverse events and change, often overlaps with other energy policy concepts such as resilience, security, poverty, justice, and sustainability. This paper improves our understanding of vulnerability in economics, energy, and sustainability studies by: **i)** constructing a dataset on energy vulnerability made of 180.000 observations; **ii)** formally defining energy vulnerability considering the regulatory framework and development agenda; **iii)** building a composite indicator on energy vulnerability; **iv)** analyzing and ranking the energy vulnerability of a vast number of OECD and non-OECD countries; **v)** testing for robustness checks. The analysis suggests that GDP is not necessarily a leading driver for energy vulnerability, whilst resource embedment is, resulting both fossil and renewable energy producers less vulnerable. It is validated that green countries are less vulnerable, differently from cold, heavily-industrialized, and highly-consuming countries.

JEL codes: C38, C43, O13, Q48

Keywords: energy vulnerability; composite indicators; principal component analysis; sustainability; robustness analysis; resilience.

Wordcount: 6214

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1. Introduction

Energy policies devoted to sustainability are in the top agenda of local governments and international institutions. Energy strategies are called to face novel concerns - namely energy poverty, security, justice, and the interconnected issues of energy resilience and vulnerability. Literature increasingly studies and discusses theories and metrics, attempting to measure different dimensions of energy vulnerability.

1.1 State of the art

Most of the studies on energy and resources security, vulnerability, and resilience are addressed either to industrialized countries (Gnansounou, 2008; Costantini et al., 2007) or less developed countries (LDC) (Morrow et al., 2018; FAO, 2016).

For the LDCs, access to electricity is a major concern. Despite improvements in the long-run, 1.06 billion people in the world still lack access to electricity, foremost in rural areas - especially Sub-Saharan Africa and Southern Asia -. It is deemed that 20 countries account for 80 percent of the global access deficit in 2014 (IEA & WB, 2017; IBRD & WB, 2017). Providing universal access to modern energy services by 2030 should be a priority. Moreover, 3.04 billion people rely on solid fuels and kerosene for cooking and heating (IEA & WB, 2017). A controversial challenge comes from the necessity for modern society to cope with the access to modern energy systems with environmental and climate change issues. These aspects related to climate justice received a wide attention in the last years, and were included as development agenda priorities, and enhanced by COP21 and subsequent climate agreements. In this context, energy strategies such as energy efficiency, CO_2 reduction, GHG emissions containment, and energy transition has taken on a decisive role.

Industrialized countries face energy vulnerability problems, also stemming from governance and regulation of natural gas and electricity markets. There is evidence of this since the 2000-2001 Western power crisis and the Enron collapse (Borenstein, 2002). The facts were caused by a series of events, including market abuses operated by Enron and other major players, episodes that are likely to have occurred along a regulatory capture (Busato & Gatto, 2019 & 2017). In the last decade, further companies were alleged for market manipulation and eventually settled with contested agreements (Markham, 2018) contributing to the sectors vulnerability.

This paper preliminarily defines **energy vulnerability** as *“the degree to which an energy system or entity is more likely to get exposed with adverse events or change, and risks to fall into traps in economic, social, environmental and governance terms”*.⁴ In this context, resilience has a pivotal role, being a measure for the system, organization, enterprise or entity to adapting and learning from continuous change (Gatto & Drago, 2019). Long-term sustainability trends are reputed essential to forecast resilience actions (Frankenberger et al., 2012). This must be attributed to the property of the former in affecting livelihood security and exposure to risks and increase vulnerability or adaptive capacity. Being multidimensional concepts, it emerges the goodness-of-fit of composite indicators to define and gauge sustainability dynamics (OECD, 2008; Nardo et al., 2005).

⁴ It is inspiring the definition of vulnerability conceived by Gnansounou (2008): “the degree to which a system is unable to cope with selected adverse events”.

(Energy) vulnerability assessment is critical for the risk analysis of key infrastructures and resource and to deliver policy recommendations. It passes through vulnerability identification of assets, criticality, and threats (U.S. Department of Energy Office of Energy Assurance, 2002). Energy vulnerability assessment is also required for establishing preparedness schemes that will ensure effective responses to pulsing challenges – including national strategies to contribute facing climate change, oil price volatility, and overall power sector vulnerability (ESMAP, 2008).

When it comes to nexuses, it holds the property of resilience to be used as a proxy of energy policy to tackle vulnerability. On the other hand, it results crucial as well the role of sustainability in defining energy vulnerability: vulnerability is related with the dimensions of sustainability, whose balance will configure the upcoming resource tracks (Khan, 2019). Sustainable energy assessments techniques are also employable as early-warning tools for policy design (Ren & Dong, 2018). Vulnerability envisages pathways to formulate resilience policies worthy to draft sustainable development futures – decisive for modelling public-private partnerships and decision-making strategies (Azapagic & Perdan, 2009).

1.2 Brief literature review

The economic literature does not uniquely characterize and perhaps does not offer a clear-cut notion for the concepts of energy vulnerability, resilience, poverty, justice, sustainability, and security (Cherp & Jewell, 2010). Nevertheless, reflexive governance corollary confirm that vulnerability, resilience, and sustainability are closely intertwined (Stirling, 2014). A clear understanding of how these concepts relate to energy policy is needed, especially since the choice of theoretical and methodological framework affects one's interpretation of the results (Sovacool, 2011; Kruyt et al, 2009; Winzer, 2012). It is worthwhile to apply this assertion to energy vulnerability, underscoring the need to define and measure a topic that remains not sufficiently delineated in the literature.

Energy is a leading driver of economic growth, employment, and sustainable development. Energy policy is a major development agenda area of action. Ensuring energy services for all is recognized as a core strategy to tackle poverty and reach energy security itself. The implementation of a modern, affordable, reliable, sustainable, and universal energy access should be among the pre-requisites for enabling virtuous economic cycles. Such access would eventually alleviate poverty, contribute protecting the environment, and building solid institutions (UN, 2015).

In September 2015, the UN launched the Agenda 2030. Within the 17 Sustainable Development Goals (SDGs), vulnerability and resilience policies play a leading role. On the other hand, energy policy was addressed through a whole Goal: SDG 7 requires to “ensure access to affordable, reliable, sustainable and modern energy for all” (UN, 2015). As part of SDG 7, they were detected 5 targets and 6 indicators with specific energy policy scopes, to be achieved by 2030. Target 7.1 proposes to “ensure universal access to affordable, reliable and modern energy services”, while Target 7.2 states to “increase substantially the share of renewable energy in the global energy mix”. For Target 7.3, it was agreed to “double the global rate of improvement in energy efficiency”, and for Target 7.A, the consensus was based on “enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy

technology". The latter relevant target, 7.B, focused on "expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programs of support".

Energy regulation affects energy vulnerability as well, since history observed energy price manipulation schemes ran across the regulation scheme. With the scope to merge national markets into a unique European energy market, the European Commission (EC) saluted a set of reforms, aiming at enhancing supply security, environmental sustainability, production efficiency and market competitiveness (Gnansounou, 2008). In regulatory terms, in the last years the EU showed to be proactive when it came to energy security regulation, implementing a series of directives and Green Papers through the EC (EC 2001a, 2001b, 2003 & 2006). The 2000-2001 US energy crisis led to a further EU regulation - the Regulation on Wholesale Energy Market Integrity and Transparency (REMIT); this aimed defending the energy markets from the risk of detrimental insider trading, market manipulation and wholesale energy markets transaction (EU, 2011).

Among the most recent EU actions, one must mention the circular economy transition package, adopted on 2 December 2015 by the EC and approved in March 2019. This industrial model foresees a new role for products and materials, passing from a linear to a circular life path. Circular economy conceives a fundamental role for energy turns: waste and resources are minimized and valorized, with the sake of stimulating innovation, growth, and occupation in a sustainable development vision (Ferrari, Gatto & Zada, 2017; Ghisellini, Cialani & Ulgiati, 2016).

To complete the picture, there is an addition stream of research focusing on indicators on energy policy; these studies explored grassroots vulnerability and resilience, energy poverty, sustainability, justice, and security; energy vulnerability also received some attentions, especially concerning the supply side. Typically, the analyses propose a simple and/or composite indicator to measure the phenomena. Though both the definition and the calculation of energy vulnerability remain not completely covered and ambiguous. The most recent indexes generally convey in attributing a crucial role to sustainability. Among the many, Patlitzianas (2008) and Badea (2010) offer a comprehensive review of various indicators, methods, and objectives, focused on sustainable energy policy.

Given these premises, this paper offers the following contributions: **1)** construction of a fully-fledged time series database collecting 12 measures of energy vulnerability for 265 countries worldwide (OECD, non-OECD countries, regions, and territories), for over 57 years (approximately 180.000 observations); **2)** the definition of a conceptual framework capable to accurately define the notion of energy vulnerability; **3)** the construction of a robust composite indicator on energy vulnerability (Global Energy Vulnerability Index, **GEVI**), considering selected dimensions of sustainability (i.e. economy, society, environment, governance);⁵ **4)** the analysis of GEVI performance over the collected data, while discussing country rankings and selected policies; **5)** the regulatory and development agenda analysis.

⁵ As in Meadows et al., 1972

The paper proceeds as follows. **Section 2** presents the Index from a methodological perspective, together with collected and used data; **Section 3** comments the main results, while **Section 4** discusses the paper in relation to the existing literature to justify the novelty of the contribution. **Section 5** concludes. **Appendixes A, B, and C** present the factor analyses and the country pillar-profiles, run for interested readers.

2. Data and methodology: the Global Energy Vulnerability Index (GEVI)

The paper proposes a **global energy vulnerability index** constructed following methodological steps suggested in the Handbook of Composite Indicators (OECD, 2008).

1	Theoretical and conceptual framework: see Section 1.
2	<p>Data selection: The proposed index is based on 2017 WB's WDI data on Energy. It is built up a dataset consisting of 265 country observations from 1960 to 2016, over twelve variables. From this dataset, this paper proposes a cross section over the most recent year displaying consistent data (i.e. the wider sample), namely 2014.</p> <p>Variables related to investment in energy with private participation and ores and metals exports were dropped from our sample since these variables are not in line with the definition of energy vulnerability, while being not capable to add significant information, not pertaining to the field, nor matching the criteria behind the indicator proposed.</p> <p>A total of 7 pillars with 12 sub-pillars have been encompassed in the GEVI.</p> <p>Selected relevant variables were collected from the 2017 edition of World Development Indicators issued by the World Bank. The collection was based on the variables from Energy & Extractives Open Data Platform. The 7 pillars detected for the index scope come from the WB's Energy & Mining featured development indicators, that provide variables related to energy policy on economic, social, and environmental dimensions worldwide. Indicators come from different sources, i.e. internal (WB), external and mixed. Each indicator has different records, showing some divergences in data collection in terms of countries and time series.</p> <p>It is possible to examine the chosen variables and pillars, with regards to the four sustainability dimensions that forged the research's theoretical framework – societal, economic, environmental, and governance -. The motivations of the data selection are pitched below.</p> <ul style="list-style-type: none"> - <i>Electricity access</i> (measured by the variables <i>access to electricity</i> and <i>time to get electricity</i>) was chosen as a major requirement to tackle energy vulnerability, a prior for societal needs. - <i>Energy intensity</i>, given by the relationship amongst Total Primary Energy Supply and GDP, has been coupled with <i>GDP per energy use</i>. They express national energy efficiency, where a high rate of energy intensity or GDP per energy use displays high substitution costs of energy into GDP. - <i>Energy import</i> is determining for energy trade. In this sense, a country that relies on energy imports has been considered as more likely to be vulnerable. - The pillar D, <i>renewable energy consumption</i>, is composed of three sub-pillars: <i>renewable energy consumption</i>, <i>alternative and nuclear energy</i>, and <i>fossil fuel consumption</i>. Considering that a cleaner consumption is associated with a lower vulnerability, the first two variables have been accounted of impacting negatively on energy vulnerability, whereas the polarity of the third was positive (affecting the environmental dimension, hence increasing vulnerability). - A greater <i>energy consumption</i> (here composed by <i>electric power consumption</i> and <i>energy use</i>) is associated with greater energy requirements and pollution, affecting both the economic and environmental sphere. - <i>Fuel export</i> is a determinant of one country's power embedment, signaling decreased vulnerability. - <i>Renewable energy output</i> is considered to smooth energy vulnerability, being a channel for energy sources diversification.
3	Data treatment: The dataset built consisting of more than 180.000 observations. Considering the vast content of the dataset, they were evaluated several techniques options for the treatment of the missing values. As recommended by the literature for similar cases (OECD, 2008), the work proceeds

	with data deletion, eliminating the observations for which 2014 was not reported. It must be noted that this decision consented to achieve a parsimonious result: they were mainly discarded data relative to regions and territories, while most of the countries were preserved. This decision allowed to keep 146 countries, representative of the vast majority of world population. Alternative methods that were evaluated for data imputation were hot and cold-deck imputation, mean/median substitution, and regression imputation for single imputation. On the other hand, the use of Monte Carlo Markov Chain (MCMC) was assessed as for multiple imputation. ⁶
4	Normalization: The standardization of the indicators was necessary to make them comparable; then Z-scores were run.
5	Weighting and aggregation: After standardizing the values to make them comparable, it is used a weighted sum, using equal weights, to make a linear aggregation and compute the seven sub-pillars chosen - somehow representative of diverse energy dimensions. Having aggregated the twelve sub-pillars into seven pillars, the computation proceeded reducing the dimensions of the pillar into the synthetic index.
6	<p>Multivariate analysis: Next, it is performed a Principal Component Analysis (PCA) as a multivariate analysis method to calculate the final index, the GEVI. PCA was performed to further reduce the dimensions of the pillars. The PCA is employed with the aim to reduce the number of variables in latent variables. PCA was employed to obtain factors explaining correlations among variables; thus, high correlations must be displayed. They are examined the outcomes of eigenvalues and explained variance, fixing a threshold for the two factors for the explanation of the total variance. Each factor is weighted by each eigenvalue, that gives a ranking.</p> <p>For the factor analysis, it was first examined the correlation matrix (see Appendix A, Table 3 - Correlation matrix) among the pillar variables significance, where they were run both the correlations between the 12 starting variables and the one-tail significance. The correlation matrix among the pillar variables significance exhibits few high correlations, as it is suitable. The correlation matrix was completed by plotting its inverse (see Appendix A, Table 4 - Inverse correlation matrix) to verify that correlations among pillars are significant. Thus, they were run a Kaiser-Meyer-Olkin (KMO) test - measure of sampling adequacy -, and a Bartlett's sphericity test, in order to evaluate the feasibility of the PCA for the analysis (see Appendix A, Table 5 - KMO and Bartlett's tests). As it can be seen from Appendix A, the Chi-square results of Bartlett's sphericity test confirms the validity of the outcoming, allowing to proceed in the exercise.</p> <p>Since the aim is to obtain factors that explain correlations among variables, the former must display high correlations. The exercise accounts for the values of eigenvalues and explained variance. Thus, it is fixed a threshold for the two factors for the explanation of the total variance. Each factor is weighted by each eigenvalue, that gives a ranking. Hence, they are examined the pillars communalities - extracted through the PCA (see Appendix A, Table 6 - Communalities). Pillars communalities suggest extracting four principal components. These outputs were consolidated graphically, representing a scree plot (see Appendix A, Figure 5 - Scree Plot). The results sketched are confirmed by the scree plot. The Kaiser criterion recommends dropping factors with eigenvalues < 1.0 (Nardo et al., 2005). The aim is to preserve cumulative data, selecting the first components. The analyses suggest that variability across all factors is best captured in four principal components as can be observed in the appendixes. The results are confirmed by the scree plot also reported in Appendix A.⁷</p> <p>More analyses were run to corroborate those tests. They were analyzed the component matrix (see Appendix A, Table 7 - Components matrix) of the 9 pillars that extracts 4 components through the PCA, the correlations reproduced - making use of the PCA - between the 9 pillars (see Appendix A, Table 8 - Correlations reproduced),. The tests allow to check for both the correlation reproduced and the residual. The study eventually provides a rotated component matrix (see Appendix A, Table 9 - Rotated</p>

⁶ In these regards, switching models for latent variables might be useful to detect the changing regimes in the business cycles and the relationship between energy crises and business cycles turning points - more precisely, that oil shocks affect the likelihood to enter a recession – (Engemann, Kliesen & Owyang, 2011).

⁷ On the graph: components number: 4; eigenvalue: 1,0

	components matrix) and a component transformation matrix of the 9 pillars (see Appendix A, Table 10 - Component transformation matrix), that in this case are worthwhile to be extracted exploiting the PCA and rotated through <i>varimax</i> with <i>Kaiser normalization</i> (Nardo et al., 2005).
7	Uncertainty and sensitivity analysis: Next, to check robustness, different weighting and aggregation schemes are computed. The goodness-of-fit of the choices was thus checked by a correlation exam between the final results/techniques adopted. Its results are presented below. This is a fundamental step to validate the exercise soundness (Drago & Gatto, 2018; Nardo et al., 2005). The following tests have been ran: i) an equal weight estimate, ii) a subjective weight based on the dimensions of sustainability (economic, social, environmental, and governance dimensions, Meadows et al., 1972), iii) and a data aggregation through the Borda method. Along these dimensions, the work aims to match the qualitative and the quantitative approach, giving a rigorous and objective rationale to define and measure the notion of energy vulnerability.
8	Relation to other indicators (see Section 4 - Discussion).
9	Decomposition into underlying indicators data representation, rankings, and comparisons between results are presented. Next, the different variables, pillars, and geographical areas are estimated. The exercise is completed making use of a set of techniques for data communication, as for diagrams, heat maps, and tables. A full discussion and representation are presented in Sections 3, 4 – Results, Discussion.
10	Visualization (see Section 3 - Results)

Table 1 eventually summarizes the structure of the GEVI Index.

	PILLAR	SUB-PILLAR
Global Energy Vulnerability Index (GEVI)	A – Electricity access	A.1) Access to electricity
		A.2) Time to get electricity
	B – Energy Intensity	B.1) Energy Intensity
		B.2) GDP per energy use
	C – Energy imports	
	D – Renewable Energy Consumption	D.1) Renewable Energy Consumption
		D.2) Alternative and Nuclear Energy
		D.3) Fossil Fuel Energy Consumption
	E – Energy Consumption	E.1) Electric Power Consumption
		E.2) Energy Use
	F – Fuel Export	

	G – Renewable Electricity Output	
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Table 1 - GEVI

3. Results

The variables define the notion of energy vulnerability in all four dimensions of sustainability (Meadows et al., 1972). The methodology is in line with existing Energy Vulnerability Index (Gnansounou, 2008): the new index relies on four out of five variables from the former index (Energy Intensity of the GDP, Energy Import Dependency, Energy-related CO_2 emissions against TPES, Electricity supply vulnerability, and Non-diversity of transport fuels). The index does not include the variable “Non-diversity of transport fuels”, used by Gnansounou.

Two remarks arise. A potential improvement of this analysis might apparently be to detect a further governance variable; though it is not included in the WDI dataset. This presumptive flaw was addressed encompassing the governance dimension of sustainability in most of the variables as a secondary dimension. Another fact to be pointed out is that several variables display different signs in terms of partial ranking, signaling that polarity is a decisive information to be evaluated in the following methodological steps.

Next figures present the selected dimension of the index.

As recursive in the composite indicators literature, **Figure 1** below plots the ten top, ten middle, and ten bottom countries from the energy vulnerability ranking, emphasizing the partial results of the seven GEVI pillars. For a graphical analysis of the singular pillars scores, one can refer to **Appendix B**. The rationale was to realize a comparative international analysis, assembling a set of best, average, and worst performers, useful to capture national classifications, keeping an eye on the pillars scores.

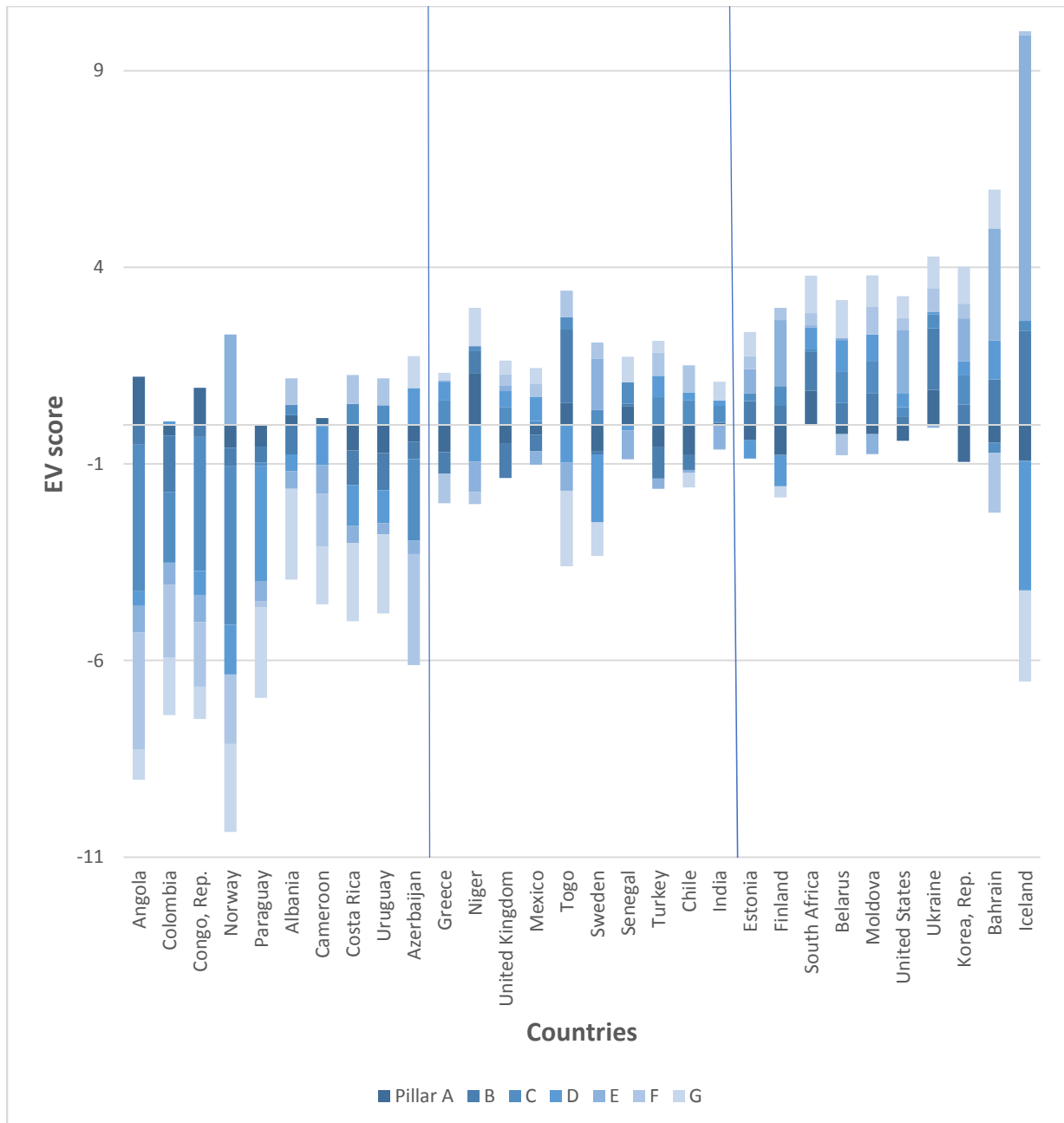


Figure 1 - Country performance for pillars

Figure 2 next, completes Figure 1 picture, presenting a spider diagram of the seven GEVI pillars for selected countries; these are representative of the different world regions, climates, development stages, energy production, and consumption and environmental attitudes and attributes. The most vulnerable country – Iceland - displays a significant heterogeneity in the performance of the single pillars: they emerge highly-differentiated results amongst the different variables: Iceland performs extremely poorly in pillars like energy consumption whilst for renewable energy consumption shows outstanding records. The best performer - Angola – takes advantage of an interesting result, due to oil production, modest consumption, and an overall good performance for each indicator. More details regarding the pillars' differentials are presented in **Appendix C**.

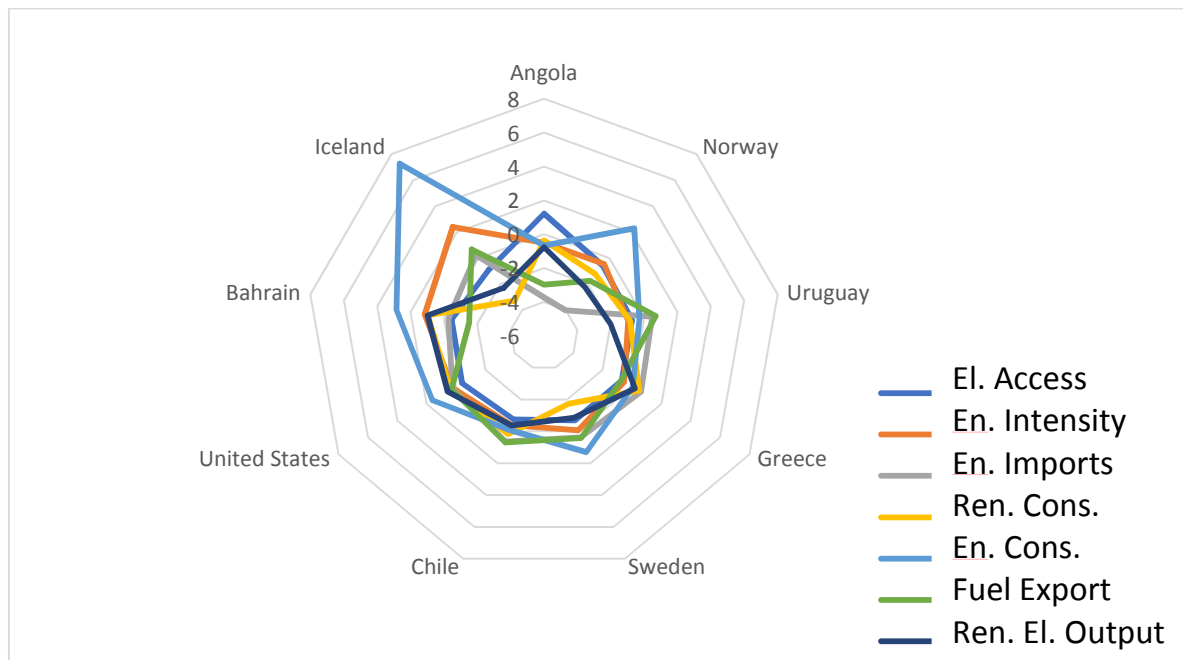


Figure 2 - Spider diagram GEVI

Whilst existing studies focused on developing countries - more precisely samples from rural villages families - (FAO, 2016), or on a set of specific industrialized countries (Gnasounou, 2008), this paper offers a global representation of the phenomenon at a macroeconomic level.

The analysis on **developing countries** furnishes a more precise overview of the concept of resilience, dealing mostly with the household component, interpreted as the center of resilience decision-making (FAO, 2016). Technically, this purpose is obtained through a survey, making use of a rotating panel for a number of Ugandan families. Some remarks raise. The years involved in the analysis are typically few (two years for each of the two samples of families, totally four years). This work benchmarks for the definition and measurement of (food) resilience and its policy implications; despite its scientific relevance, its methodology may want to benefit from an enhanced robustness for analyzing the rotating panel assessed. This is especially due to the reduced number of families surveyed, their localization - a circumscribed remote area -, and the limited time-span during which they are observed. Potential mistakes in calculation might lead to the risk of a wrong interpretation and dissemination about what a shock is and how to cope with resilience measures. Corroborating the methodology and the data collection seems to be a useful step to give a complete view of resilience and to ensure the exercise replicability. This result can be achieved by testing or comparing the technique adopted with other methodologies within a sensitivity analysis and their correlations exam. The tests could eventually decrease the potential variables multicollinearity and discharge the index from falling into a potential case-based spectrum; this would yield a more reliable composite indicator in line with the demanding scientific and policy requirements (Drago & Gatto, 2018; Agovino et al., 2018).

Studies focusing on a set of **industrialized countries** use IEA data to give a supply-side glance of energy vulnerability (Gnasounou, 2008). There are several lessons that can be

learned from this work. Namely: i) the subjectivity of the choice in weighting the pillars composing the index; and ii) the number and variance of the set of selected countries (25, all OECD). The index has been applied in World Energy Council's Europe's Vulnerability to Energy Crises (2008). Compared to 2005 IEA Statistics, 2017 WDI energy data seems to be more appropriate displaying longer, more accurate, updated, and detailed time series, succeeding in catching the energy-development nexus. Gnansounou's index presents the great merit to provide a preliminary definition of energy vulnerability, clearing the path to further research. Another good point is that, methodologically, the work prescribes the use of a Euclidean distance to the benchmark country. Though the use of subjective weighting, coupled by the lack of a robustness check and/or a sensitivity analysis, stimulates to enhance the research methodology and to pursue a further energy vulnerability index.

Figure 3 sketches the GEVI results on all the pillars. Top ten, middle ten, and bottom ten ranked countries are represented, from left to right, according to scores. The results might seem somehow surprising: among the best worldwide performers (displaying a lower vulnerability), they can be found deeply diverse countries, e.g. Angola (last energy vulnerable country), Colombia, Republic of Congo, Norway, Paraguay, Albania, Cameroon, Costa Rica, Uruguay, and Azerbaijan. On the other hand, it is noticeable Iceland (most energy vulnerable country), Bahrain, Southern Korea, Ukraine, United States, Moldova, Belarus, South Africa, Finland, and Estonia, as the most energy vulnerable worldwide countries.

The results discussed formerly are represented on a map in **Figure 4**, catching a global picture of energy vulnerability. It is not observable a geographical clustering, signaling that leading factors are not solely determined by their location or geographical attributes, whereas a combination of those factors and especially natural embedment seem to be more important in terms of energy vulnerability. As for Figure 1, the choice fell into a worldwide comparative analysis, useful to underpin selected national performances.

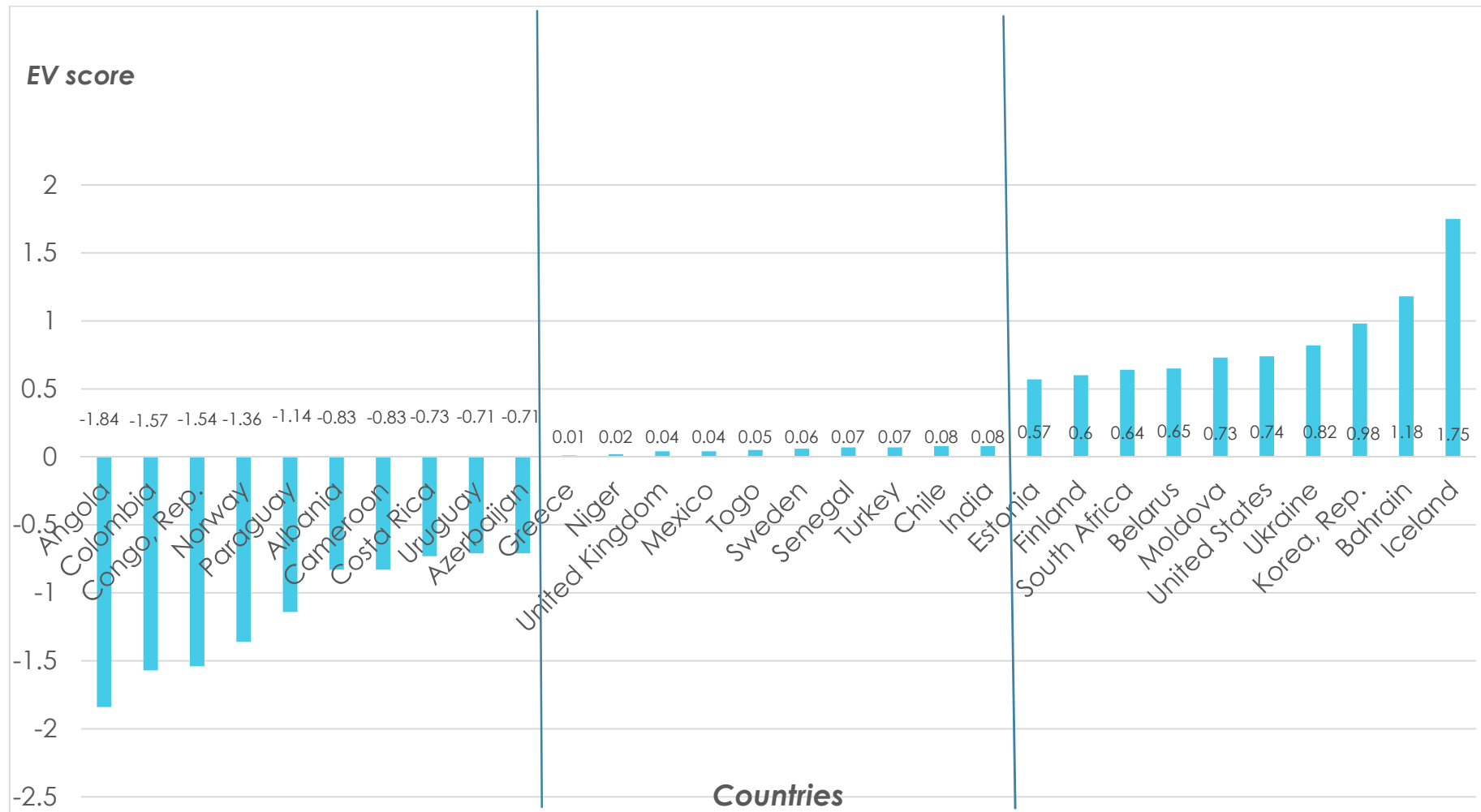


Figure 3 - Ranking GEVI

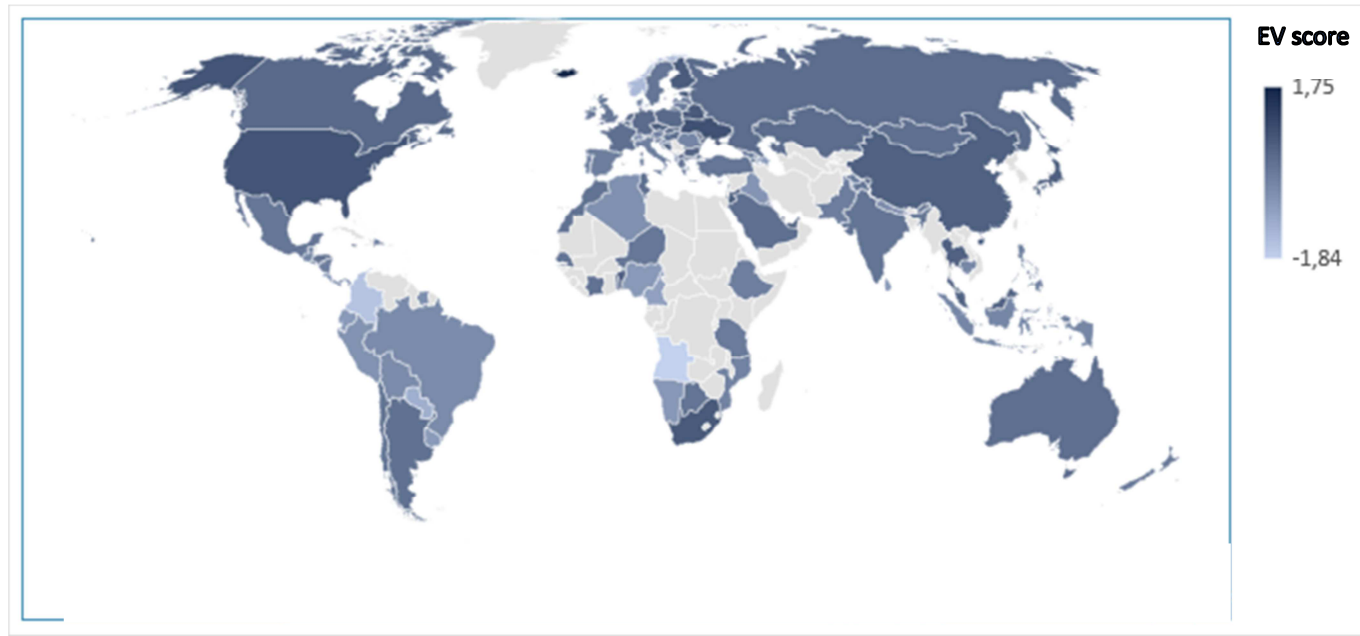


Figure 4 - GEVI map

4. Discussion

Other indexes inspired the chosen strategy, formulation, and conceptual framework. Energy vulnerability in coal mining industrial ecosystem is measured by Wang et al. (2017). The resulting benchmark index aims at evaluating the framework of energy prices volatility, whereas sustainable development is related to regional development. The index sorts 14 pillars and 33 coal mining areas in China, whilst methodologically exploits rough set-technique for order preference by similarity to ideal solution-rank-sum ratio.

The bridge between energy policy issues – and more specifically the security-vulnerability nexus - is thoroughly examined by Kendell (1998). Imports are gauged in terms of vulnerability. and applied to the oil sector, localizing the exercise to the United States. Hence, import vulnerability is deemed a proxy for energy security performance.

Other papers deal with environmental vulnerability, applied to resource economics issues – namely, agro-industrial innovations – (de Figueirêdo et al., 2010). In this case, the environmental performance is appraised by calculating an indicator that measures the vulnerability analysis of watersheds. Hence, the study adopts the Ambitec-Life Cycle method. Then, the environmental vulnerability index is run, taking into consideration the life cycle stages, as defined in the paper. Ten environmental policy issues are taken into account, and seventeen pillars are considered for the criteria of exposure, sensitivity, and capacity of response.

The index on which this study mainly relies theoretically is the synthetic index of energy demand/supply weaknesses defined as a proxy of energy vulnerability (Gnansounou, 2008). Built on five indicators, the index explores the dimensions of energy policy sustainability to detect vulnerability drivers in the EU and OECD countries. The weighting rationale is based on subjective choices, a possible methodological limitation. Albeit this potential flaw in the index composition, the work presents the benefits of advancing a statistic root, exploiting the Euclidean distance to the benchmark country - a choice that increases the index robustness.

Another vulnerability index, pitched to energy crises and applied to Europe, has been gauged by the World Energy Council (WEC, 2008). This index focuses on both the demand and the supply side and associates the vulnerability with the risk. It takes into account the sustainability dynamics.

In Percebois (2007) as well, the risk has a leading role in determining what energy vulnerability consists of. As for the index proposed in this paper Percebois attributes a leading role to regulation. Differently from the proposal, in the latter regulation accounts for price volatility, variations in exchange rates and risk of blackouts which occur within the electricity sector. In addition to these factors, the index embeds industrial, trade and technological variables, paying attention to distinguish energy vulnerability from energy dependence.

As in Gupta (2008), this work employs a multivariate analysis, i.e. the PCA, to weigh the nine variables employed in the four pillars and hence examine the countries. The PCA merges the simple indicators, already aggregated into seven pillars, to form a synthetic index, ensuring an increase in robustness and objectivity with respects to subjective choices. Thus, the

exercise makes use of Borda rule, subjective weights and equal weights to corroborate the results obtained, controlling as well for the correlations among each other results.

In terms of methodology, the energy vulnerability index that seems to be more in line with the gauging choice selected is the Oil Vulnerability Index (Gupta, 2008). This index focuses solely on the oil sector. It is based on a set of seven indicators and presents the strength of the principal component analysis (PCA) weighting. The multivariate methodological approach of the principal component technique has been adopted to combine these individual indicators into a composite index of oil vulnerability to measure the complex phenomena. Such an index captures the relative sensitivity of various economies towards developments of the international oil market, where a higher index indicates higher vulnerability. The work relaxes on a cross-section analysis over 26 net oil-importing countries. It aggregates as indicators oil trade and consumption with respects to GDP, oil reserves, dependence, and sources, as well as political risk and market liquidity. The results show that there are considerable differences in the values of individual indicators of oil vulnerability and overall oil vulnerability index among the countries (both inter and intra-regional).

The paper presented is based on the time series reconstruction for a dataset that evaluates the energy vulnerability of 265 countries; this consists of the totality of worldwide OECD and non-OECD countries, regions, and territories. The proposed index developed in this work takes into consideration the four dimensions of sustainability (economic, social, environmental, governance).⁸ The dimensions are incorporated into seven pillars and then into twelve sub-pillars. For such scope, the 2017 WB's WDI dataset on Energy and Mining is exploited. A sorting of countries with respects to energy vulnerability is eventually provided. The study is completed with a review of the energy regulation framework, with a special focus on electricity, and an SDGs analysis. Therefore, selected policy implications are discussed to clear the path to the nexus with energy resilience and its policies.

Along these dimensions, the paper contributes to the energy policy debate through the following scientific purposes: i) defining energy vulnerability; ii) measuring energy vulnerability; iii) ranking energy vulnerability globally. Further contributions of the paper regard the reconstruction of the time series on energy vulnerability variables, the assessment of the regulatory framework on energy vulnerability and the examination of WB's WDI data on Energy from OECD and non-OECD countries.

Table 2 below resumes the energy vulnerability indexes explored in this paragraph.

Index	Phenomenon	Method/rationale remarks
Energy security-energy vulnerability nexus (Kendell, 1998)	Oil import vulnerability in US	Import vulnerability as a proxy of energy security performance
Energy vulnerability index (Gnansounou, 2008)	Energy demand/supply weaknesses as a proxy of energy vulnerability in EU and OECD countries	Subjective weighting but Euclidean distance to the benchmark country

⁸ As in Meadows et al., 1972

Europe's vulnerability to energy crises (WEC, 2008)	Focus on both demand and supply	Vulnerability associated with energy crises risk. Sustainability is considered
Energy vulnerability management (Percebois, 2007)	Focus on electricity regulation. Price volatility, variations in exchange rates and risk of blackouts appraised	Energy vulnerability is distinguished from energy dependence
Oil vulnerability index (Gupta, 2008)	Vulnerability in the oil sector	Principal component analysis
Coal mining industrial ecosystem Vulnerability Index (CVI) (Wang et al., 2016)	Vulnerability in the coal mining sector	Rough Set-Technique for Order Preference by Similarity to Ideal Solution-Rank-sum Ratio
Global Energy Vulnerability Index (GEVI) (Gatto & Busato, 2019)	Worldwide energy vulnerability - 12 indicators on economic, social, environmental, and governance dimensions of energy policy	Principal component analysis corroborated by a robustness analysis on weights (subjective and equal weights), and aggregation (Borda Rule)

Table 2- Energy vulnerability indexes

The GEVI contribution with regard to existing indexes is twofold: first, it furnishes a measure of energy vulnerability whole-worldwide countries, regions, and territories, on a broad range of policy variables. Second, the GEVI provides a sound theoretical, data, and methodological framework, corroborated by a set of uncertainty analyses.

These outcomes suggest entangling a parallel outlook: besides the general ranking, one should take into account the single pillars scores. This favors clearer national economic implications and policy intuitions and motivates the implementation of a two-level composite indicator. Iceland represents an interesting case, resulting as the most vulnerable country in terms of energy consumption, and less vulnerable when it comes to renewables consumption.

Iceland can be used as a case study: the large differences remarkable in the scores of its pillars are due to diverse factors, above all: the national energy mix, the industrial structure, and the country's remote location. On one hand, the geothermal and hydroelectric sources ensure to Iceland to exploit some 98% of renewable energy on the overall consumption, being Iceland energy greenness a notable economic fact amongst development and energy practitioners. On the other hand, Icelandic industry requires a lot of energy. Apart from paper, steel, heavy and polluting industries, it is peculiar the role played by Icelandic fisheries – often showcased for its sustainable and CSR attributes. Though, all these industries, are greatly energy demanding - also in light of the country's remoteness – and call for large energy vulnerability.

Looking at the big picture, Iceland allows for more analyses if one relax on the regional performances. In this sense, the Nordic region is paramount: it classifies greatly non-vulnerable (Norway), highly non-vulnerable (Denmark), average vulnerable (Sweden), highly

vulnerable (Finland), and greatly vulnerable (Iceland) countries. This fact is mostly motivated from the diverse national resource embedment, industry structure, and location.

The outcomes from the principal component analysis are corroborated by the adoption of an uncertainty analysis. The study made use of an additional aggregation technique, i.e. the Borda ranking rule, and two further weighting schemes, namely equal weights, and subjective weights grounded on a sustainability rationale. The results yield by the sensitivity analysis confirm the methodological goodness-of-fit.

Perspective policy implications raise: a resilience approach seems to be strictly connected with energy vulnerability. Energy resilience measurement relies often on the household as the center of decision-making, being families focal for first resilience responses to face vulnerability. Resilience policies are becoming foremost in the energy sector: one can mention remittances and microfinance tailored programs, often aiming to the encouragement of mini-grid and other energy access facilitation, showed to effectively decrease the vulnerability status, empowering energy resilience, justice, and security, fighting energy poverty. These trends, combined with the findings of this work, confirm the importance of keeping a tight interconnection between the economic, social, environmental, and governance sustainability. The holistic approach promoted by the international development agenda is paving the way for a mark towards cleaner energy production systems and eventually benefit from it.

5. Conclusion

The **paper defines, measures, and ranks worldwide energy vulnerability**, addressing the increasing need to shape and compute global vulnerability and resilience for energy policy scopes. The work contributes to the literature building a tailored composite indicator on the basis of 2017 WB's WDI on Energy and Mining called **Global Energy Vulnerability Index (GEVI)**.

The **paper contributes to the knowledge on energy and resource vulnerability definition and measurement**. The principal benefits are the construction of a broad dataset entangling energy policy variables, and the conceptualization, gauging, and ranking of international energy vulnerability. The results can be discussed from a policy perspective, whereas the methodological choices have been shown their robustness. The work may be read as for future research discussions in the energy policy, sustainable development, and composite indicators literature. Further future research might include diverse data and methodologies diversions: panel data analyses to detect the underlying long run trends, or further missing values treatment, that imply germane data imputation implications.

Original model predictions emerge. The analysis proves that the GDP is not necessarily a driver for energy vulnerability, while for resilience measurement GDP represents a leading asset. This apparently counterintuitive figure is also confirmed from the fact that cold, highly consuming, inefficient, and heavy-industry-led countries are in the first positions in both energy vulnerability and resilience indexes (e.g. Iceland), while oil producing, scarcely consuming, warm, non-industrial countries, rank often as last in both types of indicators (e.g. Angola).

It is validated that resource endowment matters. Energy producers (both fossil and renewables exporters) display on average a lower vulnerability, explained from the fact that they are the least exposed countries to the risk of lacking energy resources. It is confirmed that greener countries display better results, performing well in renewables consumption. Countries lacking in electricity access present generally a high vulnerability, confirming that energy access is still a strong player of energy vulnerability.

The development agenda forged the work's research rationale in proposing to define and calculate energy vulnerability worldwide, examining energy resilience and sustainable development regulation. Though the success of policymaking relies primarily on the right definition and metrics of complex phenomena.

Journal Pre-proof

References

- Agovino, M., Cerciello, M., Gatto A. (2018). Policy Efficiency in the Field of Food Sustainability. The Adjusted Food Agriculture and Nutrition Index. *Journal of Environmental Management*.
- Ang, B. W., Choong, W. L., & Ng, T. S. (2015). Energy security: Definitions, dimensions and indexes. *Renewable and Sustainable Energy Reviews*, 42, 1077-1093.
- Azapagic, A., & Perdan, S. (2005). An integrated sustainability decision-support framework Part II: Problem analysis. *The International Journal of Sustainable Development & World Ecology*, 12(2), 112-131.
- Azevedo, S. G., Govindan, K., Carvalho, H., & Cruz-Machado, V. (2013). Ecosilient Index to assess the greenness and resilience of the upstream automotive supply chain. *Journal of Cleaner Production*, 56, 131-146.
- Badea, A. C. (2010). Energy Security Indicators. Institute for Energy Security Unit of the Joint Research Centre within the European Commission, 4.
- Banerjee, S. G., Moreno, F. A., Sinton, J., Primiani, T., & Seong, J. (2017). Regulatory indicators for sustainable energy.
- Borenstein, S. (2002). The trouble with electricity markets: understanding California's restructuring disaster. *Journal of economic perspectives*, 16(1), 191-211.
- Brown, M. T., & Ulgiati, S. (1997). Energy-based indices and ratios to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation. *Ecological engineering*, 9(1-2), 51-69.
- Busato F., Gatto A. (2019). Evidenze empiriche dai prezzi elettrici durante la crisi energetica californiana. Cattura del regolatore nel caso Enron? *Moneta e Credito*.
- Busato F., Gatto A. (2017). Cyclical behavior of electricity prices during Enron Manipulations: Energy crises and regulation. *Proceedings from the International Conference on Energy, Macroeconomics and Finance (ICEFM)*, Montpellier Business School, Montpellier, France, 2017.
- Cherp, A., & Jewell, J. (2010). Measuring energy security: From universal indicators to contextualized framework. In B. Sovacool (Ed.), *The Routledge Handbook of Energy Security* (pp. 330-355). Routledge.
- Costantini, V., F. Gracceva, A. Markandya and G. Vicini (2007). Security of energy supply: Comparing scenarios from a European perspective, *Energy Policy*, 35(1), 210–226.
- de Figueirêdo, M. C. B., Rodrigues, G. S., Caldeira-Pires, A., de Freitas Rosa, M., de Aragão, F. A. S., Vieira, V. D. P. P. B., & Mota, F. S. B. (2010). Environmental performance evaluation of agro-industrial innovations-Part 2: methodological approach for performing vulnerability analysis of watersheds. *Journal of Cleaner Production*, 18(14), 1376-1385.
- Drago C., Gatto, A. (2018). A robust approach to composite indicators exploiting interval data: The Interval-valued Global Gender Gap Index (IGGGI). *Advances in Gender and Culture Studies in Business and Economics*. 4th IPAZIA Workshop on Gender Issues, 2018, Rome, Italy, Springer. ISBN 978-3-030-00335-7

- EC (2001a). Towards a European Strategy for the Security of Energy Supply. European Communities.
- EC (2001b). Directive 2001/77/EC of the European Parliament and the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market. Official Journal of the European Communities L283/33, 27 October 2001.
- EC (2003). Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. Official Journal of the European Communities L1/65, 4 January 2003.
- EC (2006). Directive 2005/89/EC of the European Parliament and of the Council of 18 January 2006 concerning measures to safeguard security of electricity supply and infrastructures investment. L33/22, 4 February 2006.
- Engemann, K. M., Kliesen, K. L., & Owyang, M. T. (2011). Do oil shocks drive business cycles? Some US and international evidence. *Macroeconomic Dynamics*, 15(S3), 498-517.
- ESMPAP (2009). Country Energy Sector Vulnerability Assessments Program: Helping Countries Prepare an Effective Energy Sector Response.
- EU (2011). Regulation No. 1227/2011, Regulation on Wholesale Energy Market Integrity and Transparency (REMIT).
- FAO (2016). Resilience Index Measurement and Analysis – RIMA II.
- Ferrari, M., Gatto, A., Sadik-Zada, E. R. (2017). Is waste-to-energy an effective strategy to increase the resource efficiency of the economy? A panel data approach to Circular Economy in EU. Proceedings from the National Congress on Sustainability and Quality of Life, Italian Association for the Studies on Quality of Life (AIQUAV), 2017.
- Frankenberger, T., Langworthy, M., Spangler, T., Nelson, S., Campbell, J., & Njoka, J. (2012). Enhancing Resilience to Food Security Shocks.
- Gatto, A., Drago C. (2019). A taxonomy of energy resilience. Third round table, Energy Policy.
- Gatto, A., Drago C. (2018). Measuring and modeling energy resilience. Proceedings from the Workshop and Tutorial “Vulnerability and Resilience: Theories, Methodologies and Applications”: National Alliance on Sustainable Development (ASviS), University of Rome La Sapienza, 2018.
- Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11-32.
- Gnansounou, E. (2008). Assessing the energy vulnerability: Case of industrialised countries. *Energy Policy*, 36(10), 3734-3744.
- Gupta, E. (2008). Oil vulnerability index of oil-importing countries. *Energy policy*, 36(3), 1195-1211.
- Heffron, R. J., McCauley, D., & Sovacool, B. K. (2015). Resolving society’s energy trilemma through the Energy Justice Metric. *Energy Policy*, 87, 168-176.

- International Bank for Reconstruction and Development, The World Bank (2017). State Of Electricity Access Report.
- International Energy Agency and World Bank (2017). Sustainable Energy for All 2017- Progress toward Sustainable Energy. World Bank, Washington DC.
- Jansen, J. C., & Seebregts, A. J. (2010). Long-term energy services security: What is it and how can it be measured and valued?. *Energy Policy*, 38(4), 1654-1664.
- Joint Research Centre, European Commission. (2015). The Challenge of Resilience in a Globalised World.
- Kendell, J. (1998). Measures of oil import dependence
- Khan, I. (2019). Power generation expansion plan and sustainability in a developing country: a multi-criteria decision analysis. *Journal of Cleaner Production*, 220, 707-720.
- Kruyt, B., van Vuuren, D. P., De Vries, H. J. M., & Groenenberg, H. (2009). Indicators for energy security. *Energy policy*, 37(6), 2166-2181.
- Markham, J. W. (2018). Regulating the “Too Big to Jail” Financial Institutions. *Brooklyn Law Review*, 83(2), 12.
- Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. (1972). *The limits to growth*. New York, 102, 27.
- Morrow, N., Salvati, L., Colantoni, A., & Mock, N. (2018). Rooting the Future; On-Farm Trees’ Contribution to Household Energy Security and Asset Creation as a Resilient Development Pathway—Evidence from a 20-Year Panel in Rural Ethiopia. *Sustainability*, 10(12), 4716.
- Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., & Giovannini, E. (2005). *Handbook on constructing composite indicators*.
- OECD. (2008). *Handbook on constructing composite indicators: Methodology and user guide*.
- Patlitzianas, K. D., Doukas, H., Kagiannas, A. G., & Psarras, J. (2008). Sustainable energy policy indicators: Review and recommendations. *Renewable Energy*, 33(5), 966-973.
- Percebois, J. (2007). Energy vulnerability and its management. *International Journal of Energy Sector Management*, 1, 51-62.
- Ren, J., & Dong, L. (2018). Evaluation of electricity supply sustainability and security: Multi-criteria decision analysis approach. *Journal of Cleaner Production*, 172, 438-453.
- Scheepers, M., Seebregts, A., de Jong, J., & Maters, H. (2007). EU standards for energy security of supply. ECN/Clingendael International Energy Programme.
- Sovacool, B. K. (2011). Defining, measuring, and exploring energy security, in B. K. Sovacool (ed.), *The Routledge Handbook of Energy Security*, pp.1–42.
- Sovacool, B. K., & Dworkin, M. H. (2015). Energy justice: Conceptual insights and practical applications. *Applied Energy*, 142, 435-444.
- Sovacool, B. K. and I. Mukherjee (2011). Conceptualizing and measuring energy security: A synthesized approach, *Energy*, 36(8), 5343–5355.

Sterling, A. (2014). From sustainability, through diversity to transformation: towards more reflexive governance of technological vulnerability

UN, RES/70/1 (2015). Transforming our world: the 2030 agenda for sustainable development.

U.S. Department of Energy Office of Energy Assurance (2002). Vulnerability Assessment Methodology–Electric Power Infrastructure. Washington, DC.

Wang, D., Zheng, J., Song, X., Ma, G., & Liu, Y. (2017). Assessing industrial ecosystem vulnerability in the coal mining area under economic fluctuations. *Journal of cleaner production*, 142, 4019-4031.

Winzer, C. (2012). Conceptualizing energy security. *Energy policy*, 46, 36-48.

World Bank (2017). World Development Indicators 2017.

World Energy Council (2008). Europe's Vulnerability to Energy Crises.

World Energy Council (2017). World Energy Trilemma Index 2017.

Appendix A - Factor Analysis

		A) Electricity Access	B) Energy Intensity	C) Energy Imports	D)Renewable Energy Consumption	E) Energy Consumption	F) Fuel Export	G) Renewable Electricity Output
Correlation	A) Electricity Access	1,000	,371	-,140	-,258	-,380	-,187	,007
	B) Energy Intensity	,371	1,000	-,115	-,259	,217	-,123	-,008
	C) Energy Imports	-,140	-,115	1,000	-,049	-,203	,797	,008
	D)Renewable Energy Consumption	-,258	-,259	-,049	1,000	-,042	-,190	,701
	E) Energy Consumption	-,380	,217	-,203	-,042	1,000	-,113	,028
	F) Fuel Export	-,187	-,123	,797	-,190	-,113	1,000	-,217
	G) Renewable Electricity Output	,007	-,008	,008	,701	,028	-,217	1,000
Sign. (one tail)	A) Electricity Access		,000	,046	,001	,000	,012	,469
	B) Energy Intensity	,000		,084	,001	,004	,070	,463
	C) Energy Imports	,046	,084		,279	,007	,000	,462
	D)Renewable Energy Consumption	,001	,001	,279		,309	,011	,000
	E) Energy Consumption	,000	,004	,007	,309		,088	,367
	F) Fuel Export	,012	,070	,000	,011	,088		,004
	G) Renewable Electricity Output	,469	,463	,462	,000	,367	,004	

Determinant = ,064



Table 3 - Correlation matrix

	A) Electricity Access	B) Energy Intensity	C) Energy Imports	D)Renewable Energy Consumption	E) Energy Consumption	F) Fuel Export	G) Renewable Electricity Output
A) Electricity Access	1,921	-,666	,297	,825	1,006	,183	-,587
B) Energy Intensity	-,666	1,447	-,098	,307	-,559	,092	-,163
C) Energy Imports	,297	-,098	3,221	,322	,534	-2,583	-,830
D)Renewable Energy Consumption	,825	,307	,322	2,644	,485	,091	-1,853
E) Energy Consumption	1,006	-,559	,534	,485	1,630	-,123	-,428
F) Fuel Export	,183	,092	-2,583	,091	-,123	3,253	,666
G) Renewable Electricity Output	-,587	-,163	-,830	-1,853	-,428	,666	2,464

Table 4 - Inverse correlation matrix

Kaiser-Meyer-Olkin measure of sampling adequacy		,435
Bartlett's sphericity test	Chi-sq. Approx.	387,667
	gl	21
	Sign.	,000

Table 5 - KMO and Bartlett's tests

	Starting	Extraction
A) Electricity Access	1,000	,872
B) Energy Intensity	1,000	,892
C) Energy Imports	1,000	,920
D) Renewable Energy Consumption	1,000	,878
E) Energy Consumption	1,000	,900
F) Fuel Export	1,000	,906
G) Renewable Electricity Output	1,000	,904

Note: Extraction method: principal component analysis

Table 6 - Communalities

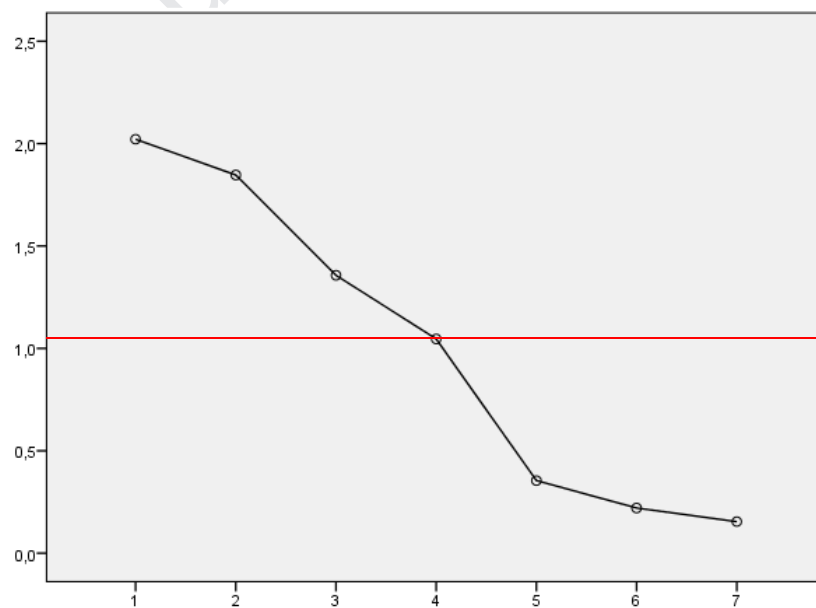


Figure 5 - Scree Plot

Note: the y axis denotes the eigenvalue, while the x axis denotes the component number

	Component			
	1	2	3	4
A) Electricity Access	-,133	-,593	,698	,127
B) Energy Intensity	-,175	-,591	,014	,715
C) Energy Imports	,801	,353	,182	,347
D)Renewable Energy Consumption	-,466	,785	,190	,091
E) Energy Consumption	-,241	-,019	-,834	,381
F) Fuel Export	,892	,223	,002	,244
G) Renewable Electricity Output	-,509	,596	,323	,430

Extraction method: principal component analysis

4 components extracted.

Table 7 - Components matrix

		A) Electricity Access	B) Energy Intensity	C) Energy Imports	D)Renewa ble Energy Consumpti on	E) Energy Consumpti on	F) Fuel Export	G) Renewable Electricity Output
Correlatio n reproduce d	A) Electricity Access	,872 ^a	,474	-,145	-,259	-,491	-,219	-,006
	B) Energy Intensity	,474	,892 ^a	-,098	-,314	,314	-,114	,049
	C) Energy Imports	-,145	-,098	,920 ^a	-,030	-,219	,879	,010
	D)Renewable Energy Consumption	-,259	-,314	-,030	,878 ^a	-,027	-,218	,806
	E) Energy Consumption	-,491	,314	-,219	-,027	,900 ^a	-,128	,006
	F) Fuel Export	-,219	-,114	,879	-,218	-,128	,906 ^a	-,216
	G) Renewable Electricity Output	-,006	,049	,010	,806	,006	-,216	,904 ^a
Residual ^b	A) Electricity Access		-,103	,005	,001	,111	,032	,012
	B) Energy Intensity	-,103		-,016	,055	-,097	-,009	-,057
	C) Energy Imports	,005	-,016		-,019	,016	-,081	-,002
	D)Renewable Energy Consumption	,001	,055	-,019		-,015	,028	-,105
	E) Energy Consumption	,111	-,097	,016	-,015		,015	,022
	F) Fuel Export	,032	-,009	-,081	,028	,015		-,001
	G) Renewable Electricity Output	,012	-,057	-,002	-,105	,022	-,001	

Extraction method: principal component analysis

Communalities reproduced

The residuals are computed among the correlations observed and reproduced. There are 7 (33,0%) non-redundant residuals with absolute values greater than 0,05.

Table 8 - Correlations reproduced

	Component			
	1	2	3	4
A) Electricity Access	-,184	-,093	-,716	,563
B) Energy Intensity	-,056	-,068	,097	,935
C) Energy Imports	,954	,052	-,077	-,037
D) Renewable Energy Consumption	-,087	,888	,047	-,281
E) Energy Consumption	-,146	-,019	,908	,232
F) Fuel Export	,930	-,182	,026	-,082
G) Renewable Electricity Output	-,037	,942	-,010	,120

Extraction method: principal component analysis

Rotation method: Varimax with Kaiser normalization.

Convergence rotation run in 5 iterations.

Table 9 - Rotated components matrix

Component	1	2	3	4
1	,852	-,488	-,097	-,162
2	,325	,722	,194	-,580
3	,103	,318	-,932	,141
4	,397	,375	,291	,786

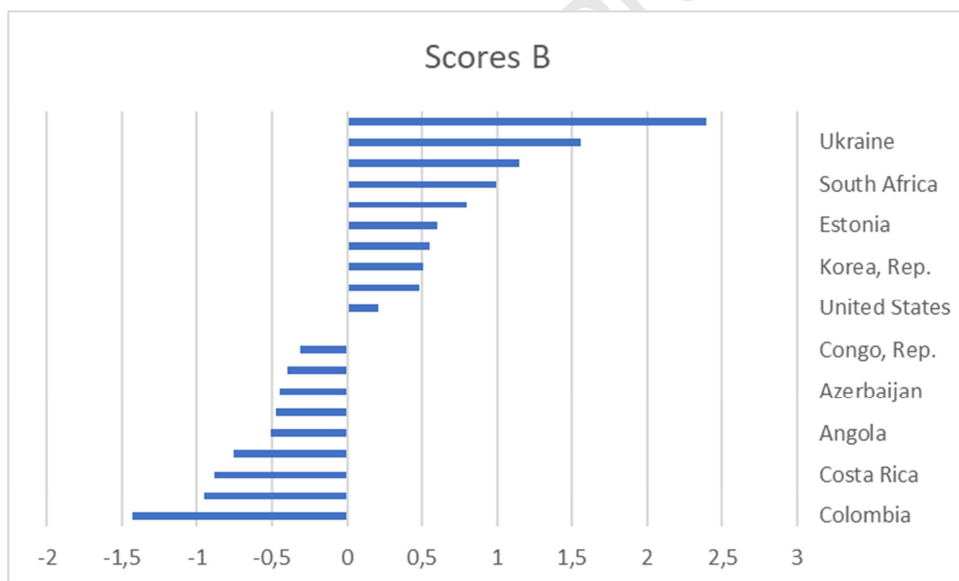
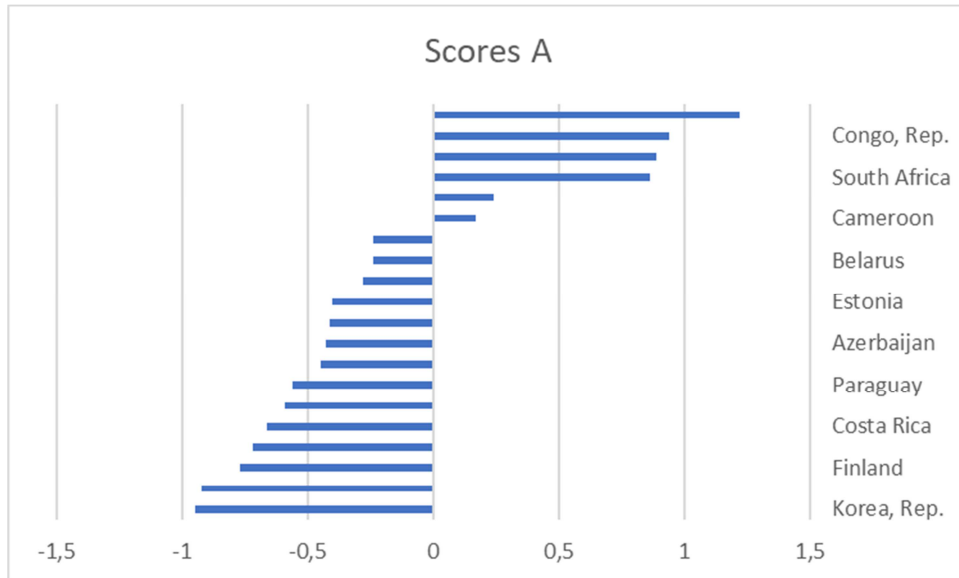
Extraction method: principal component analysis

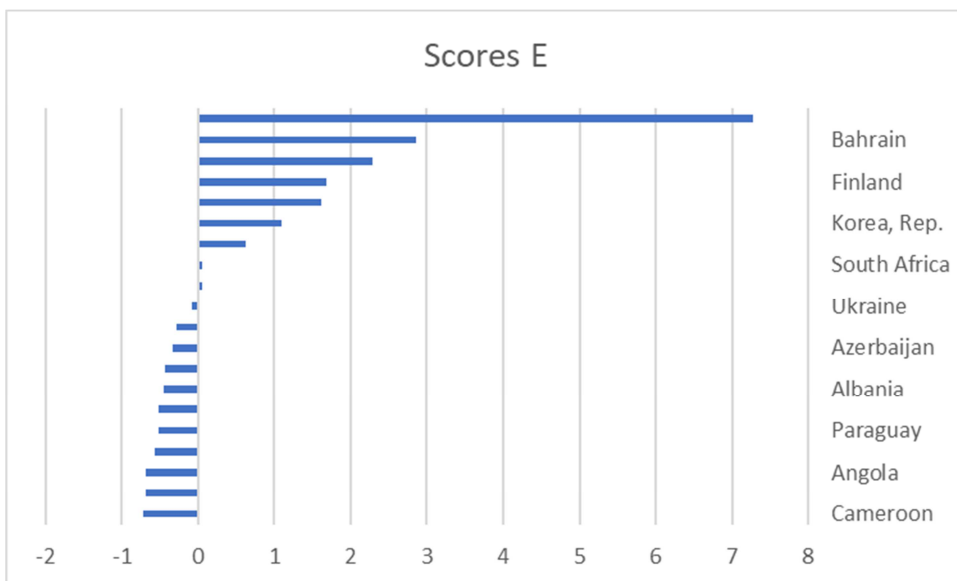
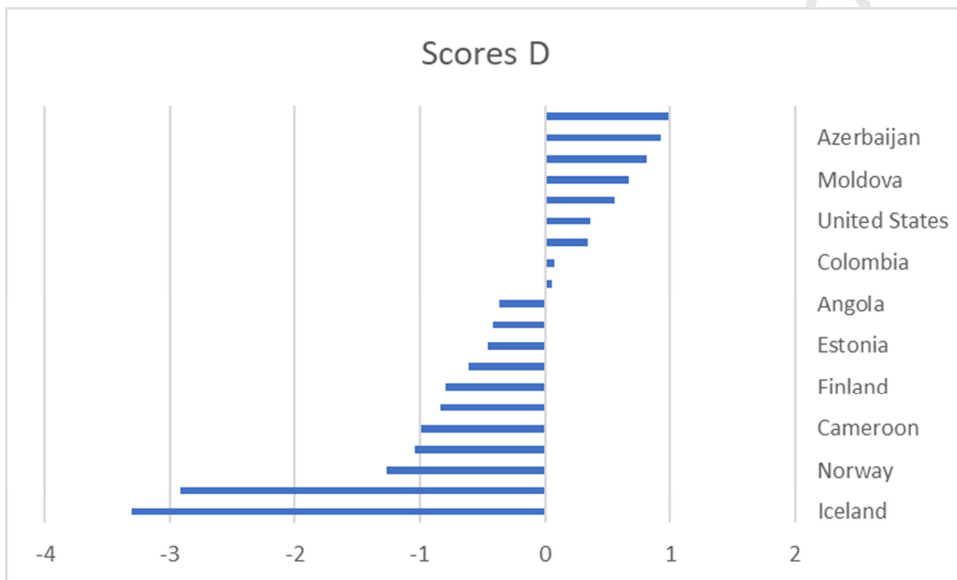
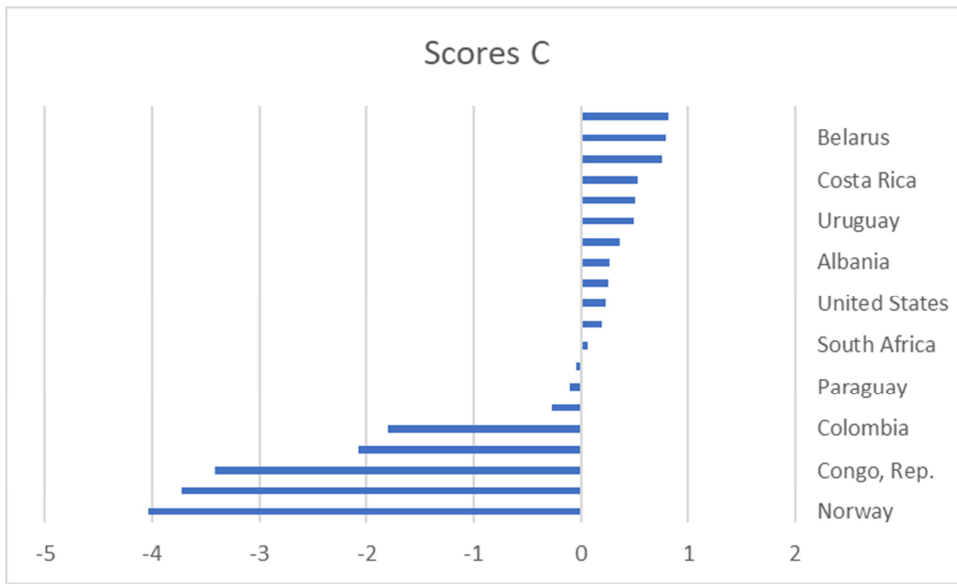
Rotation method: Varimax with Kaiser normalization.

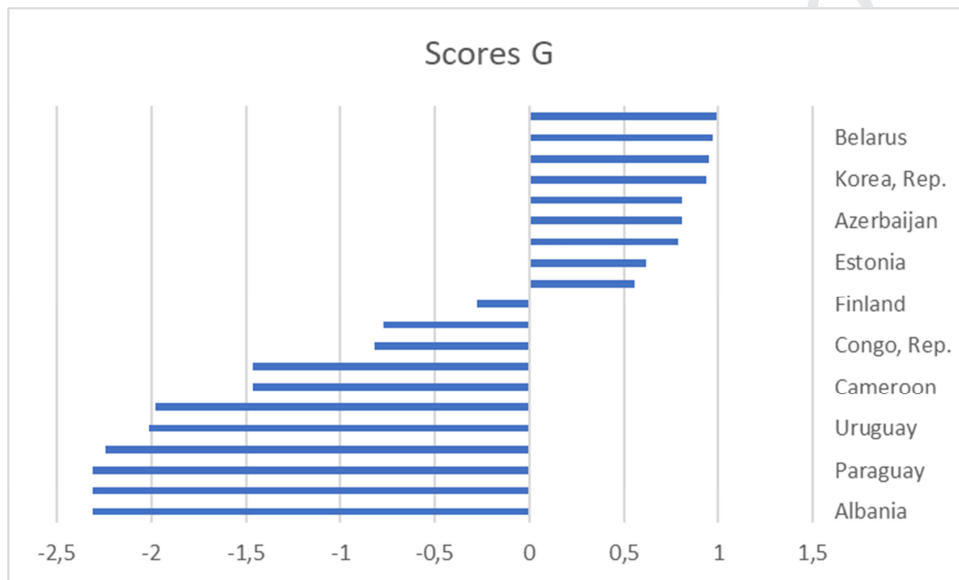
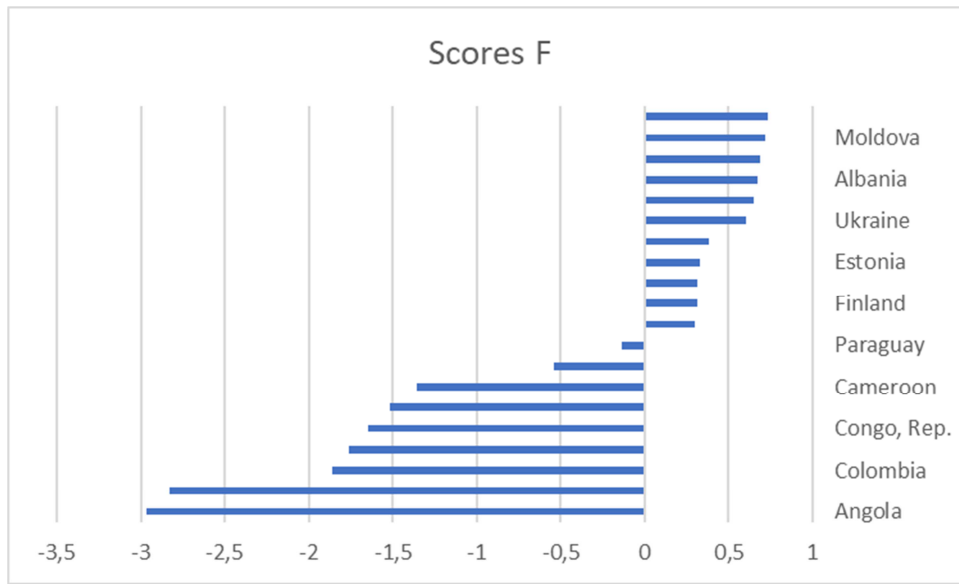
Table 10 - Component transformation matrix

Appendix B – pillar-based country profiles

Hereby are sketched the ten best and ten worst world performers in terms of energy vulnerability, according to the seven GEVI pillars presented in the text, while offering an additional and detailed perspective on the information just presented in Figure 1.

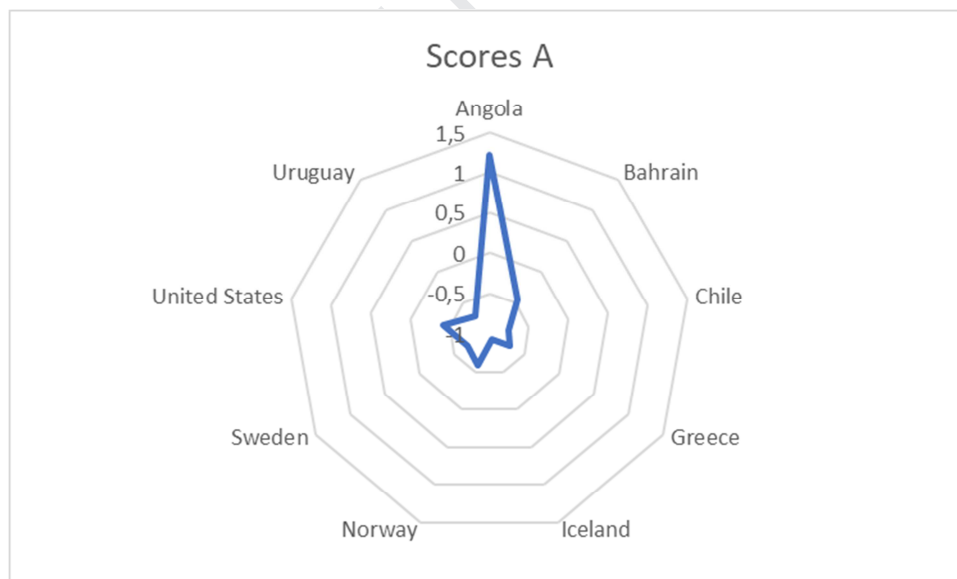
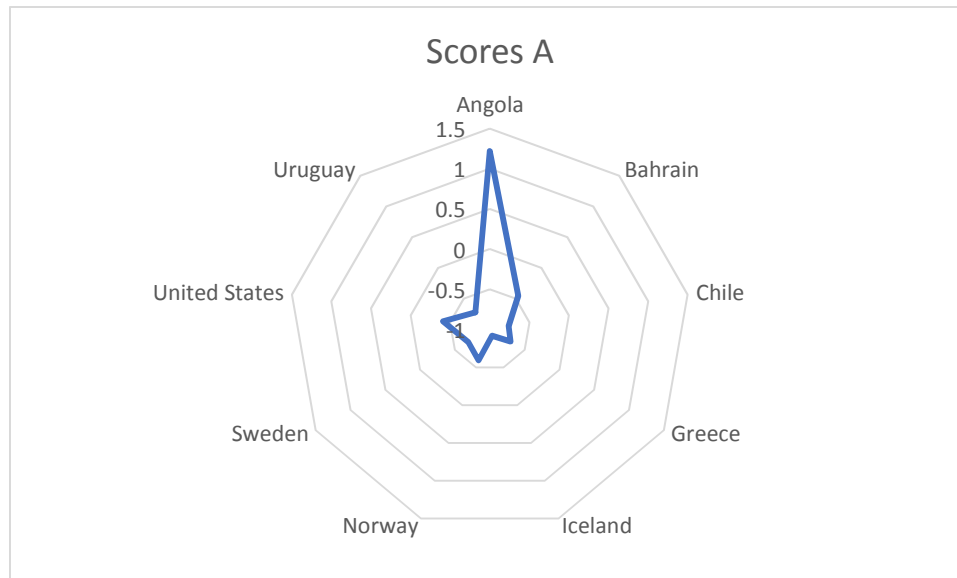


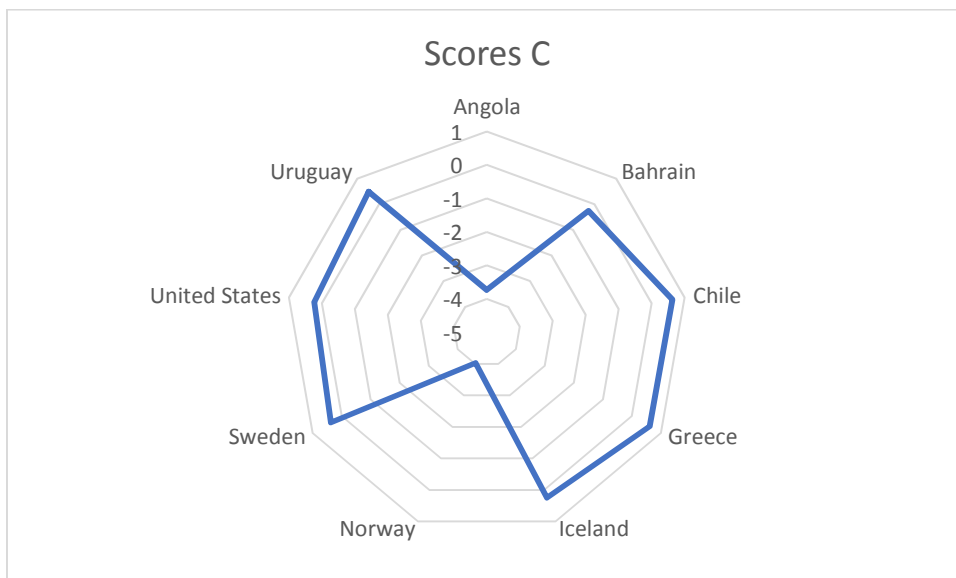
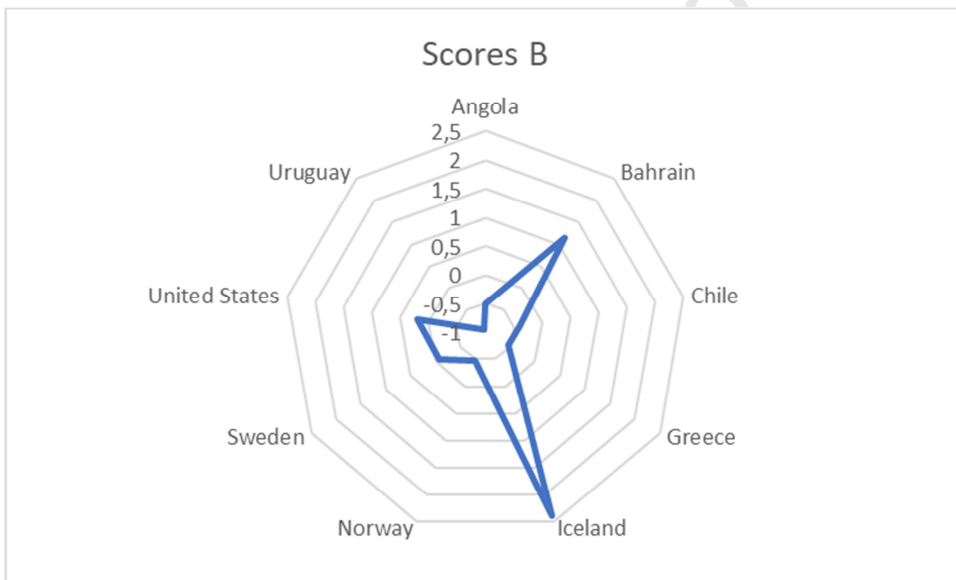
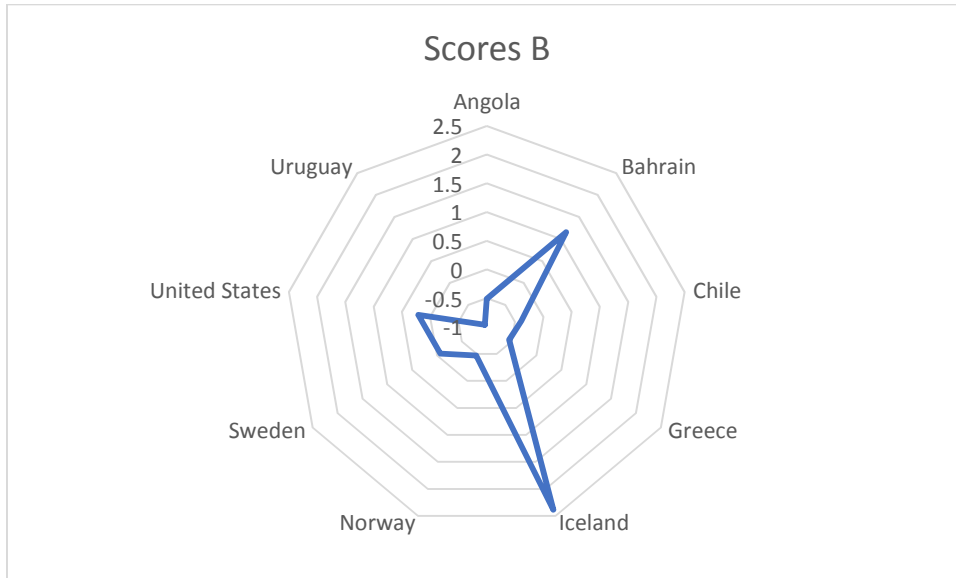


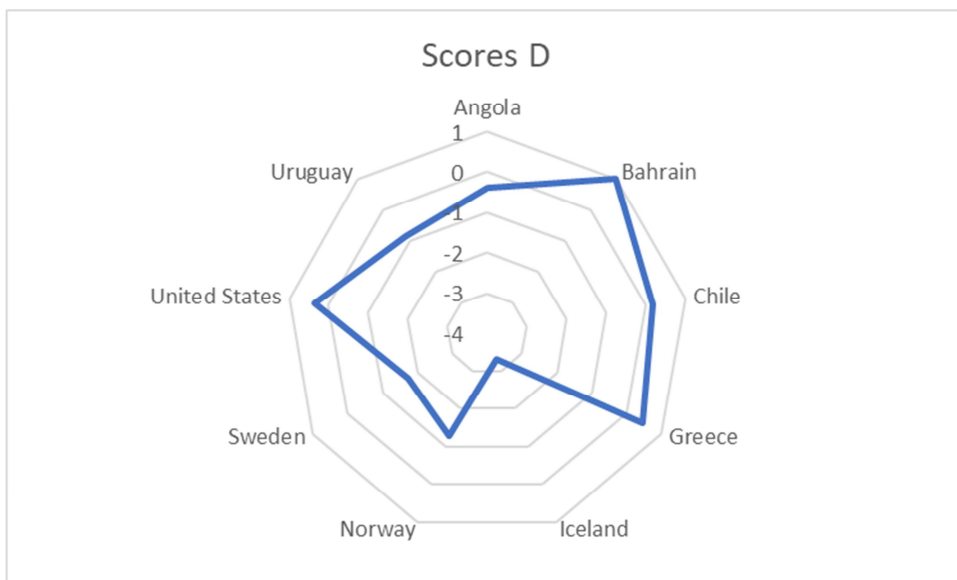
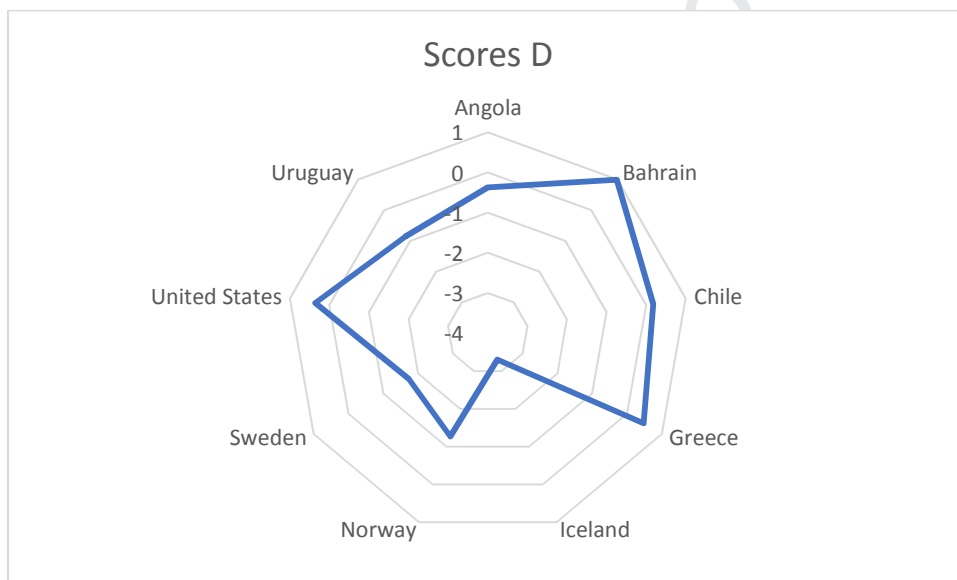
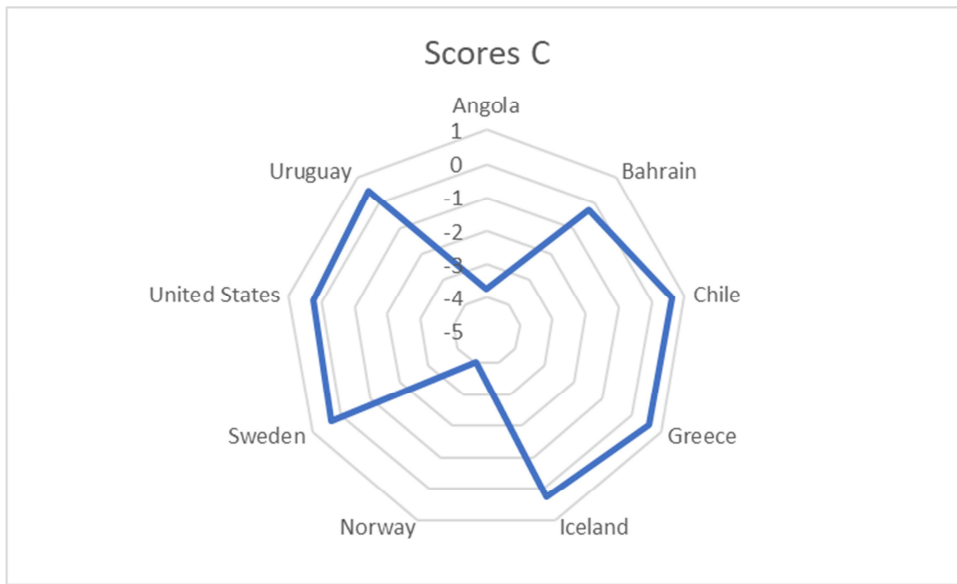


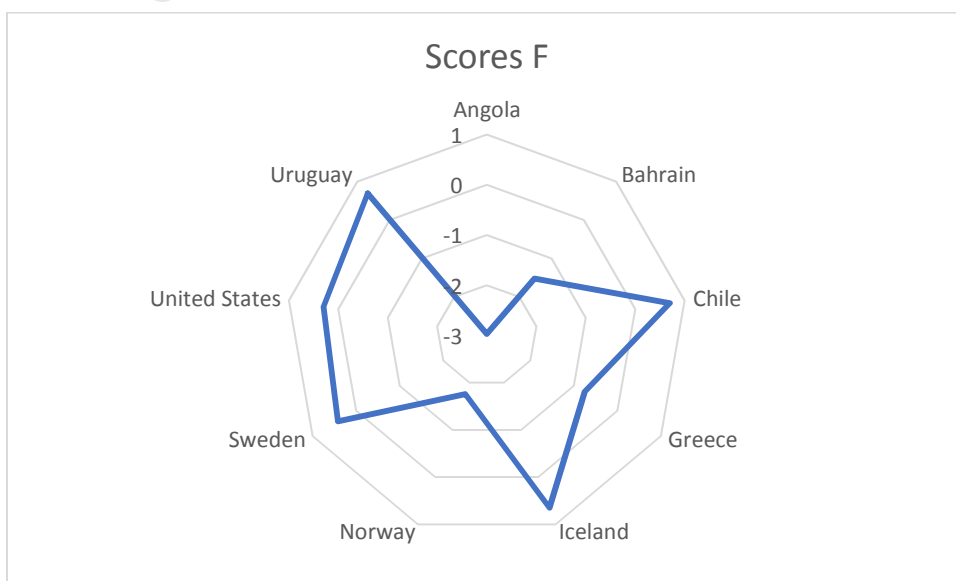
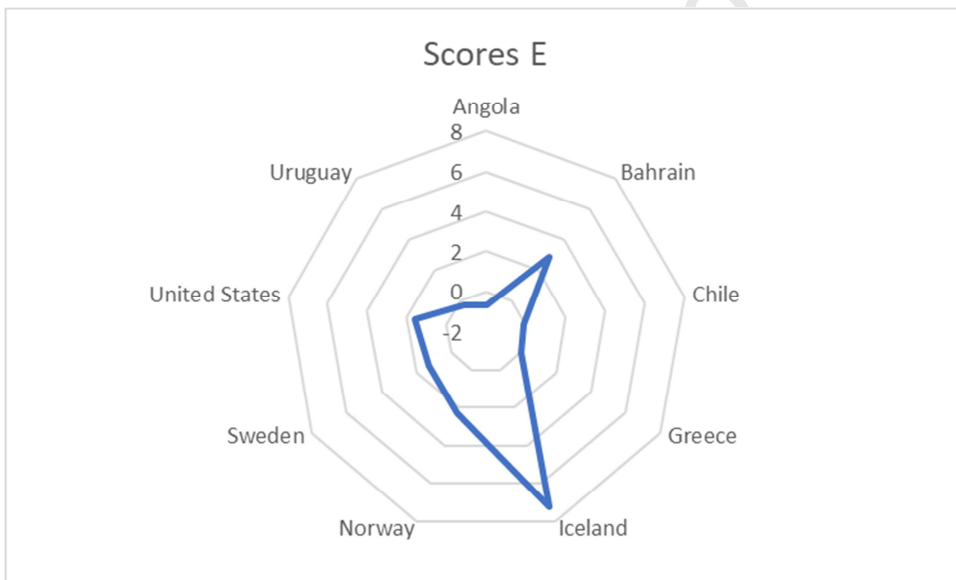
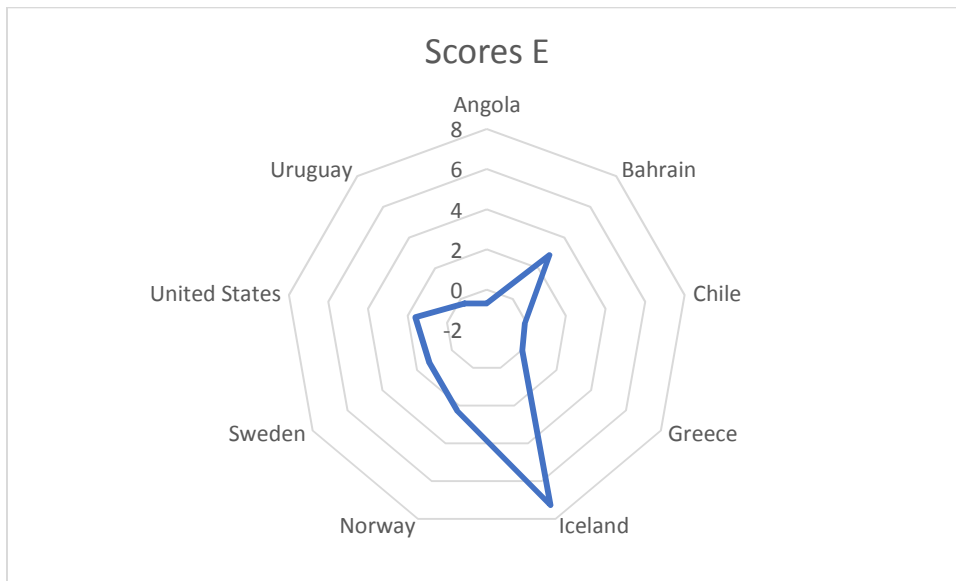
Appendix C – pillar-based country profiles

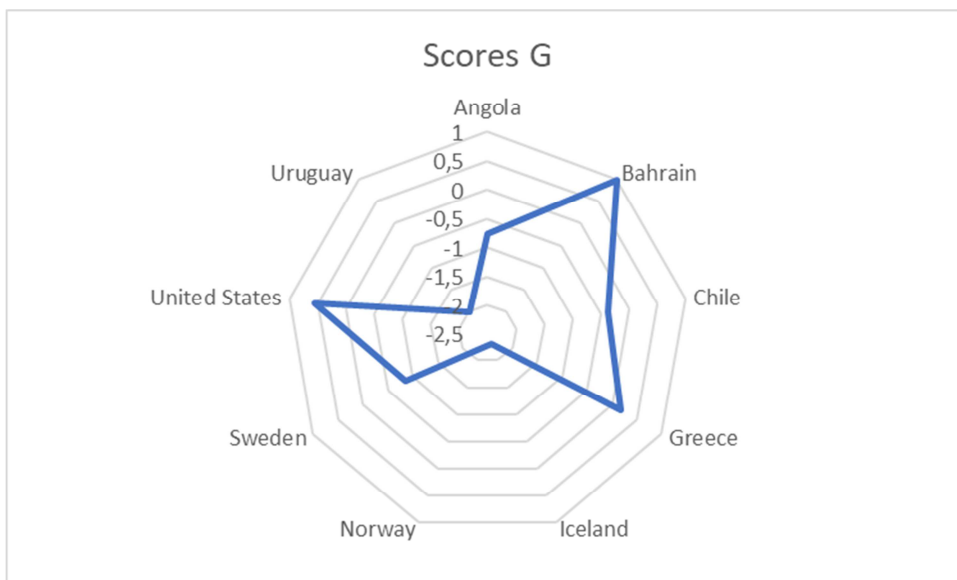
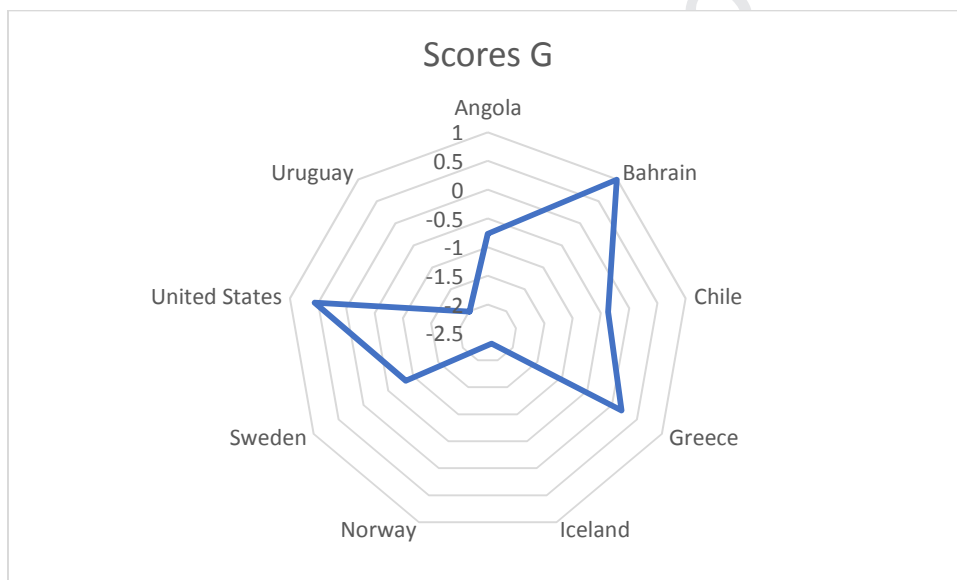
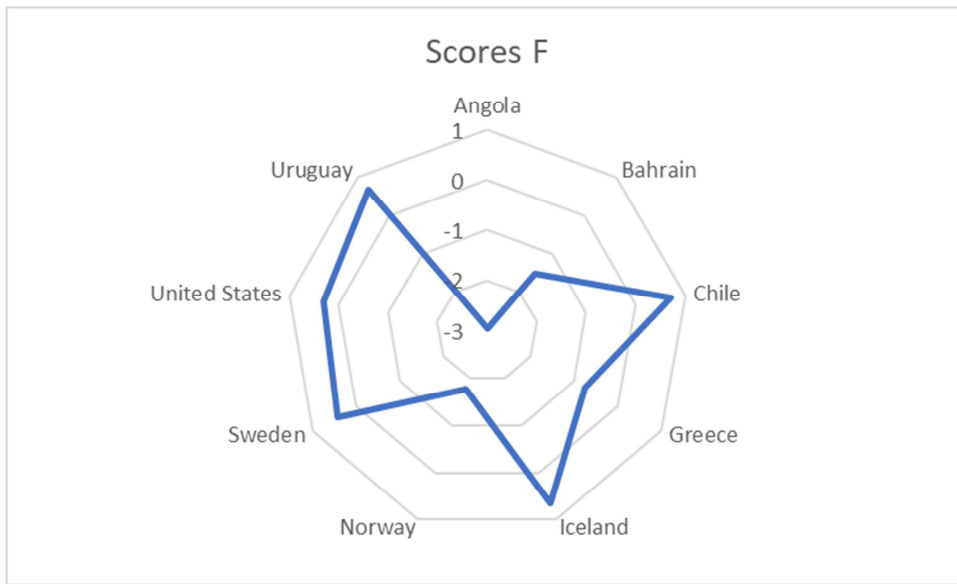
Below are sketched the ten best and ten worst world performers in terms of energy vulnerability, according to the seven GEVI pillars presented in the text, while offering an additional and detailed perspective on the information just presented in Figure 2.











Highlights

- GDP is not a strong driver for energy vulnerability;
- Green, scarcely consuming, warm, non-industrial countries perform better;
- Resource endowment and electricity access matter;
- Fossil and renewable energy exporters display a lower vulnerability;
- Rankings for the single energy vulnerability pillars vary widely.

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