International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 1076

ASSESSING THE ENERGY VULNERABILITY OF SMALL ISLAND DEVELOPING STATES

Anna Genave [1*], Stéphane Blancard [2], Sabine Garabedian [3]

1 University of La Réunion, CEMOI, 15 avenue René Cassin, La Réunion, France (*Corresponding Author)

2 CESAER, AgroSup Dijon, INRA, Univ. Bourgogne Franche-Comté, F-21000 Dijon, France

3 University of La Réunion, CEMOI, 15 avenue René Cassin, La Réunion, France

ABSTRACT

Small Island Developing States (SIDS) are afflicted by structural handicaps such as remoteness, small size and high dependence on international trade. They also share common energy challenges that jeopardize their ability to achieve a sustainable energy future. We identify factors that could potentially impact their respective energy systems such as energy import dependency and energy mix diversity. A composite index of energy vulnerability is constructed using a Multi-Layer Data Envelopment Analysis (MLDEA) approach based on eight energy indicators for 38 SIDS and other island territories. Reunion and Tuvalu make up the reference set of countries from which underperforming SIDS can benchmark best energy practices. Ultimately, this data-driven composite index of energy vulnerability can serve as useful tool for identifying priority areas that require immediate action. We recommend inter- and intra-regional cooperation between these territories based on a country clustering analysis.

Keywords: energy vulnerability; SIDS; composite index, energy security; MLDEA

1. INTRODUCTION

Energy is the ultimate commodity and pollutant (Kemmler and Spreng, 2007). An ongoing challenge for countries worldwide is to ensure the uninterrupted supply of energy in order to secure energy services for the population. In this study, we consider the energy challenges that SIDS and other island territories faces as regards their respective energy systems. The extensive reliance of SIDS on imported fossil fuels further exacerbates their exposure to external threats on international markets such as energy price fluctuations, for instance petroleum products that could be disruptive for their domestic economies, with high energy prices further burdening their national budgets. The concentration of fossil reserves in a few producing countries induce energy security concerns in case of political instability in these regions. Understanding energy system challenges becomes an essential part of energy planning and management and a first step towards mitigating energy vulnerability.

We argue that existing studies on energy vulnerability are not suitable to capture SIDS' specificities. Existing framework in the literature are incomplete, they either focus on one single source of energy (Gupta, 2008) or focus on advanced and emerging economies (Gnansounou, 2008), leaving out SIDS. We decide to build on d'Artigues and Vignolo (2012) to frame energy vulnerability. In this study, energy vulnerability comprises two main components that are exposure and shocks. We choose to leave out the adaptive capacity, i.e. the resilience of SIDS. The goal is to capture their structural vulnerability that is independent of political orientations and therefore not under their control.

The exposure component essentially captures the extent to which these territories are sensitive to potential threats (adverse events). The shock component accounts for the possible transformations these territories will undergo following a specific disturbance. Energy vulnerability thus hinders the ability of a country to provide vital energy services to its population and meet energy needs at affordable prices following internal or external disturbances. Selected indicators are thus related to the structural aspects of energy vulnerability over which countries have no control.

We thus define energy vulnerability as *'the degree of sensitivity of an energy system to external threats leading to disturbances or internal dysfunctions related to technology availability for the production, transmission and distribution of energy'*.

We focus on composite indices for their simplicity and transparency, and above all their ability to capture complex and multidimensional phenomenon like energy vulnerability. We use a Multi-Layer Data Envelopment Analysis (MLDEA) to compute the composite index. The MLDEA framework proposed by Shen *et al.* (2013) allows for endogenous weighting scheme and is considered more robust than traditional schemes such as equal weighting. Indeed, countries are assigned a set of weights which put them in the best possible position, thereby limiting countries' protests on unfair or subjective weighting schemes. Moreover, indicators belong to different categories and are further linked to one another constituting a multilayer hierarchical structure best captured by MLDEA.

We believe that the composite index can serve as a decision-making tool to help policy makers identify priority areas that require immediate attention. It also serves as a benchmarking tool for underperforming countries to learn from best practices by means of a best-practice frontier.

The remainder of this paper is organized as follows: the methodology is detailed in section 2. Results and discussion are presented in section 3. We conclude and address future research developments in section 4.

2. METHODOLOGY

The energy vulnerability index was computed for 38 territories for the year 2015 (table 1). We selected eight indicators that best capture energy vulnerability by means of a Principal Component Analysis (PCA). Figure 1 presents a four-layer hierarchical structure for the energy vulnerability concept.

The MLDEA model, as developed by Shen *et al.* (2013), is an output maximizing model with multiple outputs (i.e. indicators) and constant inputs (a single dummy input with value equal to unity is assigned to each country). Let *J* be the number of countries evaluated in terms of *s* indicators with a *K*-layered hierarchy.

Table 1 SIDS investigated by region

Regions	Countries
AIMS	Singapore (**SGP**), Bahrain (**BHR**), Seychelles (**SYC**), Mauritius (**MUS**), Reunion (**REU**), Maldives (**MDV**), Cape Verde (**CPV**), Sao Tomé and Principe (**STP**), Guinea-Bissau (**GNB**), Comoros (**COM**), Madagascar (**MDG**)
Caribbean	Trinidad and Tobago (**TTO**), Bahamas (**BHS**), Saint Kitts and Nevis (**KNA**), Antigua and Barbuda (**ATG**), Barbados (**BRB**), Suriname (**SUR**), Dominica (**DMA**), Dominican Republic (**DOM**), Grenada (**GRD**), Saint Lucia (**LCA**), Saint Vincent and the Grenadines (**VCT**), Belize (**BLZ**), Jamaica (**JAM**), Guyana (**GUY**), Cuba (**CUB**), Haiti (**HTI**)
Pacific	Palau (**PLW**), Fiji (**FJI**), Timor-Leste (**TLS**), Samoa (**WSM**), Tonga (**TON**), Papua-New-Guinea (**PNG**), Tuvalu (**TUV**), Micronesia (**FSM**), Vanuatu (**VUT**), Solomon Islands (**SLB**), Kiribati (**KIR**)

Note: AIMS stands for Atlantic, Indian Ocean, Mediterranean, and the South China Sea

Let $f_k = (1, \ldots, s^{(k)})$ be the *f*th category in the *k*th layer where $s^{(k)}$ is the number of categories in the *k*th layer. $s^{(1)} = s$, i.e. the number of categories in the first layer is equal to the number of indicators. $y_{f_k j}$ is the value for country *j* on the indicators of the *f*th category in the *k*th layer. For a country *o*, the MLDEA model can be formulated as follows:

$$CI_o = \max \sum_{f_1=1}^{s} \hat{u}_{f_1} y_{f_1 o}$$

subject to

$$\sum_{f_1=1}^{s} \hat{u}_{f_1} y_{f_1 j} \le 1, \ \ j = 1, \ldots, J$$

$$L \le \frac{\sum\limits_{f_1 \in A_{f_k}^{k}} \hat{u}_{f_1}}{\sum\limits_{f_1 \in A_{f_{k+1}}^{(k+1)}} \hat{u}_{f_1}} \le U \qquad f_k = 1, \ldots, s^{(k)}; \ k = 1, \ldots, K-1$$

$$\hat{u}_{f_1} \ge 0, \ f_1 = 1, \ldots, s$$

Where

$\hat{u}_{f_1}$	The set of optimal weights assigned to the indicators of the *f*th category in the first layer for country o obtained by solving model;
$y_{f_1 j}$ and $y_{f_1 0}$	The value for country *j* and *o* respectively, on the indicators of the *f*th category in the first layer;

$s^{(k)}$ The number of categories in the kth layer $(k = 1,2, \dots, K)$.

L and U represent the lower and upper limits imposed on corresponding internal weights with 30% of variability. The main idea is to aggregate the values of the indicators within a particular category of a particular layer by the weighted sum approach in which the sum of the internal weights equals one.

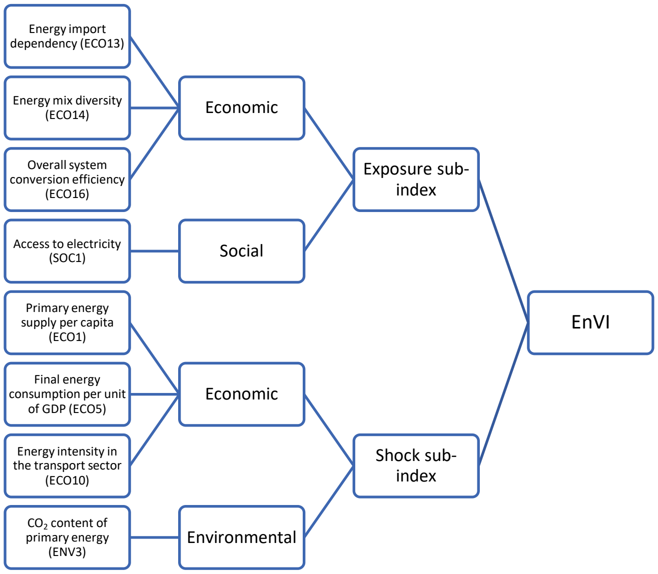

Figure 1 Hierarchical structure of the composite index
Source: authors

3. RESULTS AND DISCUSSION

The composite index should be interpreted as an index of non-vulnerability since the higher the index score, the better the overall performance of the country under investigation based on selected indicators. MLDEA results reflect relative vulnerability since the performance of a country is benchmarked on other countries' performances in the data set. Countries are ranked from most to least vulnerable. The Federal States of Micronesia had the worst energy performance with a score of 0.705. Figure 2 reports the final MLDEA scores for all countries.

Both Reunion and Tuvalu obtained the optimal score of one, which represents a lower bound on vulnerability given the set of optimal weights assigned to each country. They make up the reference set of countries (i.e. a hypothetical composite country) and provide useful benchmarks for underperforming ones to learn from best energy practices.

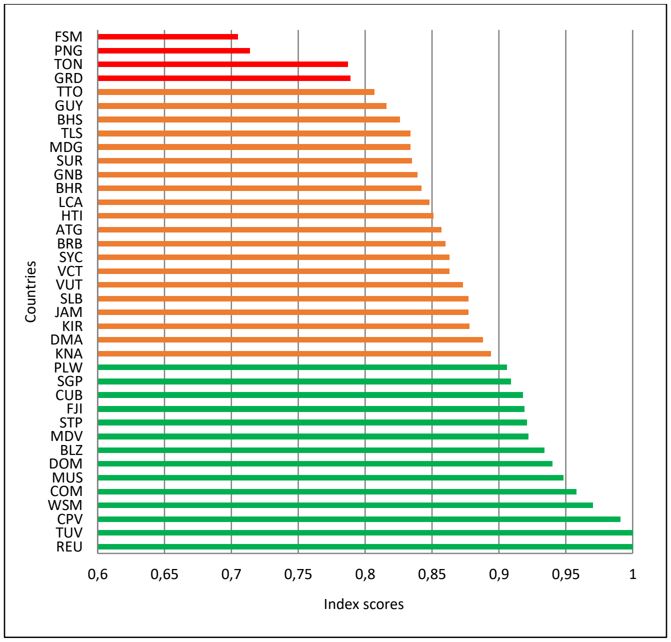

Figure 2 MLDEA index scores
Source: authors

The set of weights determined endogenously based on each country's relative performance reveal policy priorities that these territories could use to define trade-offs. For those countries obtaining less favorable scores under MLDEA, the composite index acts as an incentive instead of a punishment for lagging countries to improve overall performance. Out of the 11 islands and territories in the AIMS region, six of them ranked in the top ten best performing countries.

Table 2 Country clustering

Clusters	Countries
1	Trinidad and Tobago (**TTO**)
2	Bahrain (**BHR**) and Singapore (**SGP**)
3	Antigua and Barbuda (**ATG**), Bahamas (**BHS**), Barbados (**BRB**), Dominica (**DMA**), Grenada (**GRD**), Guyana (**GUY**), Jamaica (**JAM**), Maldives (**MDV**), Micronesia (**FSM**), Palau (**PLW**), Saint Kitts and Nevis (**KNA**), Saint Lucia (**LCA**), Saint Vincent and the Grenadines (**VCT**), Seychelles (**SYC**), Tonga (**TON**)
4	Guinea-Bissau (**GNB**), Haiti (**HTI**), Madagascar (**MDG**), Papua-New-Guinea (**PNG**), Solomon Islands (**SLB**), Vanuatu (**VUT**)
5	Belize (**BLZ**), Cape Verde (**CPV**), Comoros (**COM**), Dominican Republic (**DOM**), Cuba (**CUB**), Fiji (**FJI**), Kiribati (**KIR**), Mauritius (**MUS**), Reunion (**REU**), Samoa (**WSM**), Sao Tomé and Principe (**STP**), Suriname (**SUR**), Timor-Leste (**TLS**), Tuvalu (**TUV**)

As a complementary analysis to MLDEA, we operated a hierarchical country clustering based on similar energy practices. Following the clustering analysis, we obtained five optimal clusters. We believe that clustering is particularly useful to design tailored energy policies in this case.

Trinidad and Tobago is a net oil exporting country, accounting for a lower energy import dependency rate. The latter however has a primary energy mix dominated by fossil fuels and is relatively less efficient in converting primary energy into useful energy. Bahrain and Singapore form the second cluster (group 2). On average, they had altogether the least energy intensive transport sector, but were less efficient in terms of overall energy conversion. Most Caribbean islands are clustered in group 3. This group had a relatively concentrated energy mix mainly dominated by imported fossil energy. Based on indicator weights, we recommend that SIDS in groups 1, 2 and 3 focus on diversification strategies and to some extent invest in more efficient technologies to avoid system losses during the conversion processes.

Most SIDS identified as least developed countries by the United Nations were clustered in group 4. This group is characterized by a low level of GDP per capita. Priority areas for this group is the provision of universal access of cheap electricity to the population since on average, they are less dependent on foreign sources of energy compared to their island counterparts.

Group 5 comprised of the best-performing countries with those obtaining relatively higher MLDEA scores. Reunion and Tuvalu, identified as leaders were also in this group. The latter should address the overall system conversion efficiency to reduce transformation losses. Efforts should also be diverted towards diversifying the primary energy mix, with Reunion acting as a useful benchmark in this particular dimension.

4. CONCLUSION

We assessed the relative energy vulnerability of SIDS based on their respective energy performances in several dimensions. We adopted a ‘benefit-of-the-doubt’ approach under the MLDEA framework with no a priori knowledge on trade-offs between indicators required. Uncertainty about fossil fuel prices and their availability can be disruptive to SIDS economic prosperity and development. Ultimately, we recommend that SIDS focus on diversifying their domestic energy mix to reduce dependency on imported fossil fuels by integrating more indigenous renewable energy sources into the mix. Our contribution was thus two-fold: (1) conceptual by setting a proper framework for energy vulnerability and (2) methodological by using a combination of PCA and MLDEA, two data-driven objective methods to construct a composite index. No such index has been computed before to characterize energy vulnerability for this special group of countries.

Future research could include the extension of this study to other groups like advanced countries and developing ones to expand knowledge about this complex and multidimensional phenomenon. It would be useful to determine critical thresholds under which a country is considered vulnerable since absolute security (i.e. zero vulnerability) is almost impossible to achieve considering uncertainties surrounding the evolution of energy systems.

ACKNOWLEDGEMENT

We are grateful to anonymous reviewers for their valuable comments and suggestions on this paper.

REFERENCE

[1] Kemmler, A., & Spreng, D. (2007). Energy indicators for tracking sustainability in developing countries. Energy policy, 35(4), 2466-2480.

[2] Gupta, E. (2008). Oil vulnerability index of oil-importing countries. Energy policy, 36(3), 1195-1211.

[3] Gnansounou, E. (2008). Assessing the energy vulnerability: Case of industrialised countries. Energy Policy, 36(10), 3734-3744.

[4] d’Artigues, A., & Vignolo, T. (2012). Une approche multicritère de la vulnérabilité énergétique. Montpellier : Centre de Recherche en Economie et Droit de l’Energie (CREDEN)

[5] Shen, Y., Hermans, E., Brijs, T., & Wets, G. (2013). Data envelopment analysis for composite indicators: A multiple layer model. Social Indicators Research, 114(2), 739-756.