Diversity or Concentration of Sources in the Management of the Energy Trilemma? The Case of India

Belén del-Río, Ana Fernández-Sainz, and Itziar Martinez de Alegria

Abstract—**Energy sources have been crucial for development, but also form the backbone of what is today one of the greatest global challenges. Implementing policies to address simultaneously the three issues of the "energy trilemma" — energy security, energy equity (energy poverty) and environmental sustainability (climate change) — is one of the major challenges for policy makers. Access to and management of countries' natural resources and energy assets have played a central role in national and international politics. This paper examines the influence of the diversity of India's energy matrix on the balance of these three energy issues between 1990-2014. An econometric model confirms that diversity is statistically significant for all other variables. It also shows interesting results when analyzing its effect on each variable individually and on all of them simultaneously.**

Index Terms—**Climate change, energy governance, energy poverty, energy security, energy sources, energy trilemma, sustainability, India.**

I. Introduction

One way of studying the development of societies is through the use of energy sources. Development has always been accompanied by an increase in total energy consumption, especially of fossil fuels. But the side effects of that use or abuse represent today one of the greatest global challenges [1]–[3].

Different authors have tried to identify the full range of objectives of the energy governance. Among them all, three particularly prominent: energy security, energy equity (affordability and accessibility) and environmental sustainability. They constitute the so-called "energy trilemma" [4] which provides a clear framework to deliver the energy transformation needed. Delivering policies which simultaneously address all three issues is one of today's most arduous challenges.

The diversity on the composition of the energy mix is essential for the long-term stability and survival of a system [5]. Closely associated with sustainability and precaution in energy strategies, it implies less concentration as it extends choice of energy sources (supply side) and energy use (demand side) and increases competition. In energy policy, diversity of sources and/or suppliers is seen as part of an informed and reasoned response to supply risks. Thus, as stated by different authors, it is often used as a key indicator for assessing energy security [5]–[11], efficiency of energy use [6] financial risk, the environment and how to catalyze innovation [7]. Diversity is best achieved by a mix of fuel sources and by a preference for domestic supplies [12].

This works analyses how energy diversity (in this case that of India from 1990 to 2014) affects simultaneously all three issues of energy trilemma. The rest of the text is organized as follows: Section II briefly describes the concept of "energy trilemma". Section III presents the general methodology and data of the study while describing the situation of India). Section IV describes the econometric methodology and Section V the results and the discussion. Finally, some conclusions are presented in Section VI.

II. The "Energy Trilemma"

Different authors have tried to identify the full range of objectives of energy governance. For example, Florini and Sovacool [13] analysing the relations between the provision of energy services and the deployment of technologies with the geopolitical, environmental and economic dimensions, suggest five goals: 1) geopolitics and security; 2) transboundary externalities; 3) the political economy of energy; 4) development and energy; and 5) emerging issues in global governance and energy policy. Cherp, Jewell and Goldthau [14] observe the historical context and the political agenda to stablish a three-dimensional system made by 1) energy security; 2) access to energy (energy poverty); and 3) climate change. Dubash and Florini [15] scrutinise global political pronouncements emanating from meetings, mandates and policy statements of international institutions, and initiatives of nonstate actors and multi-stakeholder networks and group these objectives under four headings: 1) energy supply security; 2) energy poverty; 3) environmental sustainability; 4) domestic good governance and corruption. Goldthau [16] identifies four key dimensions: 1) markets, 2) security, 3) sustainability; and 4) development.

Of all objectives identified, three — energy security, energy equity (affordability and accessibility) and environmental sustainability (climate change) — constitute what is known as the ``energy trilemma''. Energy security is a crucial political issue due to the high cost of buying energy and the insecurity resulting from the political instability of exporting countries. The production and use of energy (mainly, but not exclusively, from fossil sources) has a

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negative impact on the environment. The effects of climate change will be devastating if this impact is not mitigated and effectively managed. Energy poverty has become a key social issue. Access to energy is closely linked to both economic growth and human development, yet it has not been an integral part of international political processes linked to energy, but rather tied to other objectives such as quality of life, opportunities and sustainable development [15].

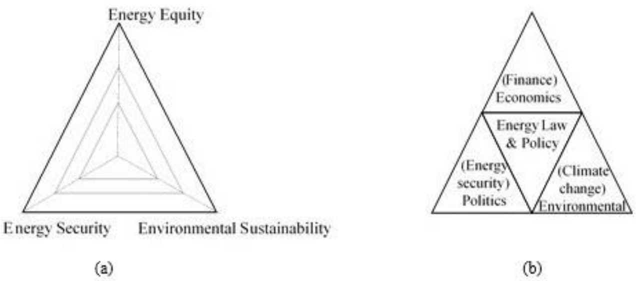

Fig. 1. Energy trilemma (a) and Energy triangle (b).

A number of authors identify the energy trilemma with the three points of the energy triangle, where energy law and policy are at the center of the triangle and at the three points are economics (finance), politics (energy security) and the environment (climate change mitigation) (see Fig. 1). However, there is a distinction between them regarding economic aspects. While the energy trilemma focuses only in the energy equity, the energy triangle broadly emphasizes financial issues. Also, energy law and politics pursues the achievement of the goals of societies, to either increase energy security and/or economic benefits and/or environmental objectives while the energy trilemma shows the *un*balance between the results of the measures taken. They do have a similarity in that each of the points tries to pull energy law and policies towards it. A well-designed energy legislation and policy should equilibrate these three objectives to provide the best result for society. A holistic method is becoming essential since no "political action" will have only a positive outcome and it is therefore important to also take into account possible negative outcomes in the other areas. Yet often the energy agenda is dominated by just one of these issues, mostly economics [2], [17], [18].

III. The "Energy Trilemma" in India

Primary energy consumption in India has increased by nearly 170% since 1990. It is the third biggest energy consuming country, yet its per capita energy consumption is considerably lower than that of large consumers at one-third of the world average. India, with a higher energy consumption than production, an estimated 240 million people without access to electricity and ongoing international pressure for further mitigation measures, faces major energy challenges.

A. Variables

For the purpose of our study, we have identified four variables: the diversity of the energy matrix (*Diversity Index (DI)*) is the independent variable; energy security (*Energy Security Index (ESI)*), environmental sustainability/climate change (*Emissions Index (EEI)*) and energy equity in terms of energy poverty (*Energy Development Index (EDI)*) are the three dependent variables. Each variable offers a value in the range of 0 to 1. Data used was sourced from IEA energy balances [19], the Emissions Database for Global Atmospheric Research [20] and the World Development Indicators Database [21].

1) *Diversity Index (DI):* A country's energy mix refers to the various types of Primary Energy Sources (PES) used to meet its energy needs. For the purposes of this study, we have considered eight types of PES: Coal, Oil (crude oil and petroleum products), Natural Gas, Nuclear, Hydro, Other Renewables, Biomass and Electricity (imported). Though the ratio representing (imported) electricity is rather small, it has been included as a PES because it forms part of the electricity consumption data used to calculate the *EDI Index*. The *DI* is calculated with Stirling's Diversity Index.

$$StI = \sum_{ij(i \neq j)}^{N} d_{ij} p_i p_j \quad (1)$$

where: N is the total number of species (from i to j); d_{ij} is the disparity between species i and species j (the Euclidean difference); p_i is the proportion of species i; and p_j is the proportion of species j

$$\text{Variety:} \quad V = \sum_i p_i^0 \quad (2)$$

$$\text{Balance: } B = \frac{1}{V}\sqrt{\sum\left(p_1 - \frac{1}{v}\right)^2} \quad (3)$$

$$\text{Disparity : } D = \sum_{ij} dij \quad (4)$$

2) *Energy Security Index (ESI):* The *ESI* is calculated by measuring India's primary energy demand (PED) using the Net Energy Import Dependency (NEID) index. The PED is calculated by assessing both domestic production and the net imports of the sources. Net imports are defined as imports minus exports.

$$NEID = 1 - \left(\frac{SWI_{import\ reflective}}{SWI}\right) = 1 - \left(\frac{-\sum(c_i p_i ln_i)/_{lnN}}{-\sum(p_i ln_i)/_{lnN}}\right) \quad (5)$$

where: c_i is the correction factor for p_i ($c_i = 1 - m_i$); m_i is the share of net imports in PES of source i; p_i is the share of PES i in TPES; i = 1...N is the primary energy source index (N is the number of PES); and lnN is the maximum possible value (as we use eight PES the lnN= 2.079).

3) *Emissions Index (EI):* As our *EI* we have chosen the Emission Intensity Indicator, which is the level of GHG emissions (CO_2) per unit of economic activity (GDP).

Energy intensity *Carbon factor*

$$\frac{CO_2}{GDP} = \frac{TPES}{GDP} \times \frac{CO_2}{TPES} \quad (6)$$

4) *Energy Development Index (EDI):* Energy poverty is assessed in terms of access to clean, affordable, stable energy services, with reliable supply and consistent quality.

$$EDI = \frac{Household + Community}{2} = \frac{\frac{\sqrt{(a+b)}+c}{2} + \frac{d+e}{2}}{2} \quad (7)$$

where: a is the electrification rate of households; b is the residential electricity consumption per capita; *c* is the share of modern fuels in total final residential consumption; *d* is the electricity consumption per capita of public services; and *e* is the share of economic energy uses in total final consumption.

B. Indian Outlook

As Fig. 2 shows, India's *DI* decreased over the years (from 0.159 to 0.129), albeit at different rates and in a more pronounced fashion from the mid-2000s onwards. This can be explained by the increase in the consumption of oil, coal (whose Euclidean distance is 0) and natural gas and the decrease in biofuels. In that time, India's *ESI* has worsened over the years, mostly driven by an increase in consumption (especially of fossil fuels); *EI* has improved slightly due to India's GDP growth which has counterbalanced the increase in emissions; and the *EDI* also indicates an improvement, albeit insufficient.

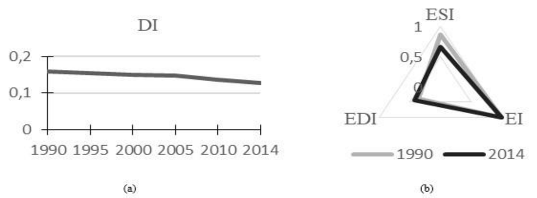

Fig. 2. Evolution of Indian Diversity Index (a) and Energy trilemma (b).

IV. Econometric Methodology

To estimate the cause-and-effect relationship between the *DI*, *ESI*, *EI* and *EDI* we propose a regression analysis.

After verifying the strong relationship between all the variables, the hypothesis that *DI* is statistically significant in *ESI*, *EI* and *EDI* has been tested. *DI* is the independent variable and the other three are the dependent variables. The following equation system has been drawn up:

$$y_{jt} = \alpha_j + \beta_j x_t + \mu_{jt}; \tag{8}$$

$$t = 1 \dots . T; \quad j = 1 \dots .3$$

where: x_t is the independent variable: *DI;* $y_{j\ (j=1,2,3)}$ are the dependent variables: *ESI*, *EI* and *EDI;* β_j are the parameters to be estimated; μ is the error term.

The cross-effects between all these variables have also been analysed to see how changes in the *DI* aimed at improving one of the dependent variables (e.g. *ESI*) affected each of the other two (*EI* and *EDI*). It also shows the effect that these two other variables, *ceteris paribus*, have on the dependent variable analysed. To that end, the following system of equations was designed:

$$y_{jt} = \alpha + \beta_{j1} x_t + \sum_{\substack{j \neq s \\ s=1}}^{3} \beta_{js} y_{st} + \mu_{1t}; \tag{9}$$

$$t = 1 \dots . T; \quad j = 1 \dots .3$$

In the specification proposed, the effect of the *DI* is allowed to be different in the three equations.

V. Results and Discussion

As pointed out above all indices provide a value between 0-1. It should be noted that for the *ESI* and *EI* a value closer to 0 means more security and a lower emissions intensity, while for the *DI* and *EDI* a value closer to 0 means less diversity and more energy poverty.

The results of the first part of the analysis demonstrate that *DI* can be considered as one of the main factors in the changes in the variables studied as well as the high statistical significance of diversity in all cases. It is interesting to remark that the increase in *DI* (greater diversity) implies an improvement in security but a worsening in both the environmental and energy development situation.

The last part of the study analyses the variables jointly, i.e. we postulate that the *DI*, *EI* and *EDI* are possible explanatory variables for the *ESI*. The results show a change in the significance and sign of the *DI* from the previous analysis. This is the case when the *ESI* and the *EI* are taken as the dependent variable. There, the increase in diversity implies a worsening of energy security (not statistically relevant) but an improvement in the environmental issue (statistically low relevance).

As for the rest of the results, we can also point out that the *ESI* is only statistically significant in the case of the *EI*, although with a negative effect, i.e. an increase leads to a rise in the *ESI*. The *EI* is a significant explanatory variable with a negative effect on both energy security and energy development, i.e. a higher *EI* increases the *ESI* and decreases the *EDI*. As for *EDI*, it is statistically significant for *ESI* and *EI*, but with a negative effect on the former and considerably positive on the latter.

TABLE I: OLS and Seemingly Unrelated Regression Equations (FGLS)

Explanatory variables	Dependent variable					
	ESI		EI		EDI	
	OLS	SURE	OLS	SURE	OLS	SURE
Constant	−6.95801 *** (0.245)	0.03420** (0.013)	0.06031*** (0.006)	−0.02574 (0.035)	−2.09800*** (0.054)	0.00259** (0.001)
DI	--	0.31464 (1.045)	--	−4.20304* (2.395)	--	−0.27944*** (0.075)
ESI	--	--	--	0.936755* (0.466)	--	0.0175168 (0.0181)
EI	--	0.16577* (0.082)	--	--	--	−0.01618** (0.007)
EDI	--	2.20455 (2.273)	--	−11.50570** (5.179)	--	--
R-square	0.96992	0.03099	0.81416	0.18128	0.98372	0.34276
T	25	24	25	24	25	24

Note: Standard deviation in brackets. Significance level: *(10%), **(5%), ***(1%)

VI. Conclusion

Delivering policies which simultaneously address them is one of the most arduous challenges for policy-makers. The `Energy Trilemma' provides a clear framework to deliver the energy transformation needed.

The aim of the study is to analyze how energy diversity (in this case that of India from 1990 to 2014) affects simultaneously all three issues of energy trilemma.

Analyses of the trend in each variable over that period show that India's energy policies have prioritized the economic development of the country, at least in the short term. Consequently, the *DI* shows less diversity driven by the increase in coal and oil consumption (India has abundant coal reserves and its transport sector has grown considerably) and insufficient efforts in renewables-based energy production.

The results of the econometric study confirm the strong link between the three issues (energy security, emissions intensity and energy development) and the statistical significance of the diversity of the energy mix in them.

The equation-by-equation analysis reveals that an increase in *ID* has a significant negative effect on *IE* and *IDE* and a significant positive effect on *ISE*, i.e. as the diversity of its energy matrix increases, India's energy security will improve, but emissions intensity and energy development will worsen.

On the other hand, when a cross-effect analysis is conducted some results for the *DI* change, in both significance and sign. This shows the importance of considering all four variables together.

The unexpected and sometimes contradictory results obtained do not allow a conclusive assessment of the effectiveness and appropriateness of the energy policies adopted by India. However, they are thought to illustrate the importance of more in-depth studies integrating all dimensions. Further work is recommended to better explain them, e.g. the study of the effects of the *DI* on the main individual variables that affect each of the three issues of the energy trilemma.

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