Analyzing the input-output efficiency of Water-Energy-Food Nexus in Brazil: a time-spatial approach

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Abstract

Understanding the effects of water, energy, and food (WEF) consumption and production on socio-economic and environmental indicators has become a strategic issue for all countries, especially the developing ones, that depend on natural resources to promote economic growth. Our main objective with this study is to quantify and understand the interconnections (Nexus) of WEF production and consumption with regional economic growth and social development in Brazil. We use a multi input-output approach based on a Data Envelopment Analysis (DEA) model to calculate efficiency indicators over time for various municipalities in Brazil. We assume that a high input-output efficiency level indicates that a certain municipality can reach larger output benefits with less WEF consumption. The time-based approach using the Malmquist Index model enables us determining whether cities' WEF input-output efficiencies have been rising or declining over time. The time-spatial analysis is appropriate to indicate the level of interdependence between WEF-Nexus and the demographic, economic, and environmental systems in Brazil. We expect that our results can help policymakers establishing regional and city-level policies that can benefit a more efficient use of WEF resources.

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1. INTRODUCTION AND OBJECTIVES

Due to the increase in world population, governments around the world have faced several challenges to promote economic and social development. Understanding the interactions among the water, energy and food (W-E-F) sectors is complex and consists in one of the key aspects used by public policies that focus on sustainable economic growth and development. Analyzing the role of W-E-F-Nexus on social and economic variables is especially important in developing countries where the effects of a more recent industrialization are related to environmental changes and to a higher demand for W-E-F. Due to the W-E-F Nexus complexity, several studies have used various quantitative and qualitative approaches to represent interconnections among variables and decision-making units. However, only few studies were able to deliver objective results to support policymakers to evaluate their actions, and to implement programs aiming to promote development with better use of limited resources. Our goal with this paper is to analyze the W-E-F Nexus for 27 state capitals in Brazil (the decision-making units – DMUs), using a framework based on efficiency. Our main objective is to calculate efficiency scores for all DMUs using the human development index (HDI) as output, and several W-E-F variables as inputs. We use the DEA methodology to calculate scores for three periods and compare their dynamics over time

2. MATERIAL AND METHODS

A. The W-E-F Nexus and the Human Development Index (HDI)

We use the W-E-F Nexus framework as input in a Data Envelopment Analysis (DEA), and define the Human Development Index as the output.

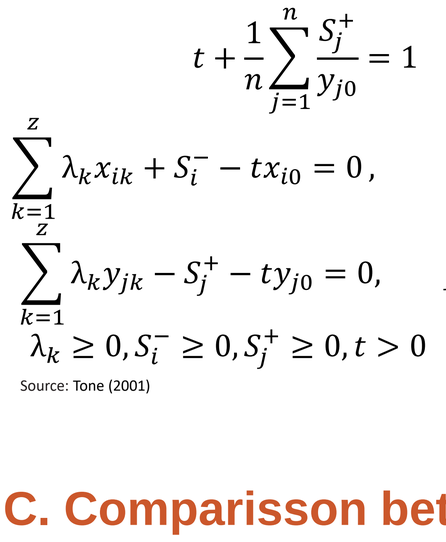

Figure 1 – W-E-F Framework
Source: SESYNC (2019)

W-E-F (Inputs)	Description (per capita/year)
WATER	Water use (m^3)
	Water waste (production – consumption)
ENERGY	Electric energy consumption (MWh)
FOOD	Food waste (1,000 m^3)
OTHER	Gas emission (tons of CO2e)
Output	**Description**
HDI-M	Municipal Human Development Index

B. Efficiency Analysis: Slack-Based Measure DEA

$$\min \quad \tau = t - \frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{x_{i0}}$$

s.t.:

$$t + \frac{1}{n}\sum_{j=1}^{n}\frac{S_j^+}{y_{j0}} = 1$$

$$\sum_{k=1}^{z}\lambda_k x_{ik} + S_i^- - t x_{i0} = 0\,, \qquad i = 1.\ldots.m$$

$$\sum_{k=1}^{z}\lambda_k y_{jk} - S_j^+ - t y_{j0} = 0, \qquad j = 1.\ldots.n$$

$$\lambda_k \geq 0, S_i^- \geq 0, S_j^+ \geq 0, t > 0$$

Source: Tone (2001)

- τ : Efficiency of $DMU0$
- t : Linearization variable
- S_i^-: Slack of ith input from $DMU0$
- S_j^+: Slack of jth output from $DMU0$
- λ_k: Contribution of kth DMU to $DMU0$
- x_{ik}: ith input from kth DMU
- y_{jk}: jth output from kth DMU
- $K = 0$: indicates DMU under analysis
- m: number of inputs
- n: number of outputs
- z: number of $DMUs$

C. Comparisson between DMUs and periods

We used the DEA efficiency scores to classify the DMUs into three groups: low, average and high efficiency. We used this classification to build a Markov Transition Probability Matrix as follows:

		t = 1		
		Low (L)	**Average (A)**	**High (H)**
t = 0	**Low (L)**	$P(L, t_1/L, t_0)$	$P(A, t_1/L, t_0)$	$P(H, t_1/L, t_0)$
	Average (A)	$P(L, t_1/A, t_0)$	$P(A, t_1/A, t_0)$	$P(H, t_1/A, t_0)$
	High (H)	$P(L, t_1/H, t_0)$	$P(A, t_1/H, t_0)$	$P(H, t_1/H, t_0)$

3. RESULTS

D. Ranking based on the efficiency scores

Region	State	Rank 2002/03	Rank 2008/09	Rank 2017/18
CW	DF	1	1	1
	GO	15	22	25
	MS	14	1	13
	MT	26	1	23
North	AC	1	1	15
	AM	27	1	1
	AP	1	1	1
	PA	17	1	21
	RO	25	17	1
	RR	21	19	24
	TO	23	1	26
South	PR	1	25	19
	RS	1	16	12
	SC	19	23	16

Region	State	Rank 2002/03	Rank 2008/09	Rank 2017/18
Northeast	AL	1	1	1
	BA	24	14	20
	CE	1	1	1
	MA	1	27	1
	PB	1	1	1
	PE	1	1	14
	PI	1	1	1
	RN	18	15	17
	SE	16	18	18
Southeast	ES	22	24	27
	MG	1	26	1
	RJ	20	20	22
	SP	1	21	1

E. Transition Probability Matrices

		2008/2009			
		Low (L)	**Average (A)**	**High (H)**	**Total**
2002/2003	**Low (L)**	0,17	0,33	0,50	6
	Average (A)	0,29	0,57	0,14	7
	High (H)	0,21	0,14	0,64	14

		2017/2018			
		Low (L)	**Average (A)**	**High (H)**	**Total**
2008/2009	**Low (L)**	0,33	0,33	0,33	6
	Average (A)	0,25	0,50	0,25	8
	High (H)	0,15	0,31	0,54	13

Convergence states (24 years): [Low = 0,23 Average = 0,39 High = 0,38]

4. CONCLUSIONS

Brazilian cities presented relative high efficiency scores in our W-E-F Nexus analysis using the HDI as output between 2002 and 2018. However, there are several locations that have not improved their efficiency levels during this period. According to the DEA analysis, the capitals of the states that worsened their efficiencies from 2003 to 2009 were the ones that had the higest Malmquist Productive Index (MPI) evolution from 2009 to 2018, because the worsts positions did not mainained their technological gain. Therefore, Brazilian policymakers should focus their actions on investments that could bring benefits in the use of W-E-F and consequently increase HDI levels.

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