

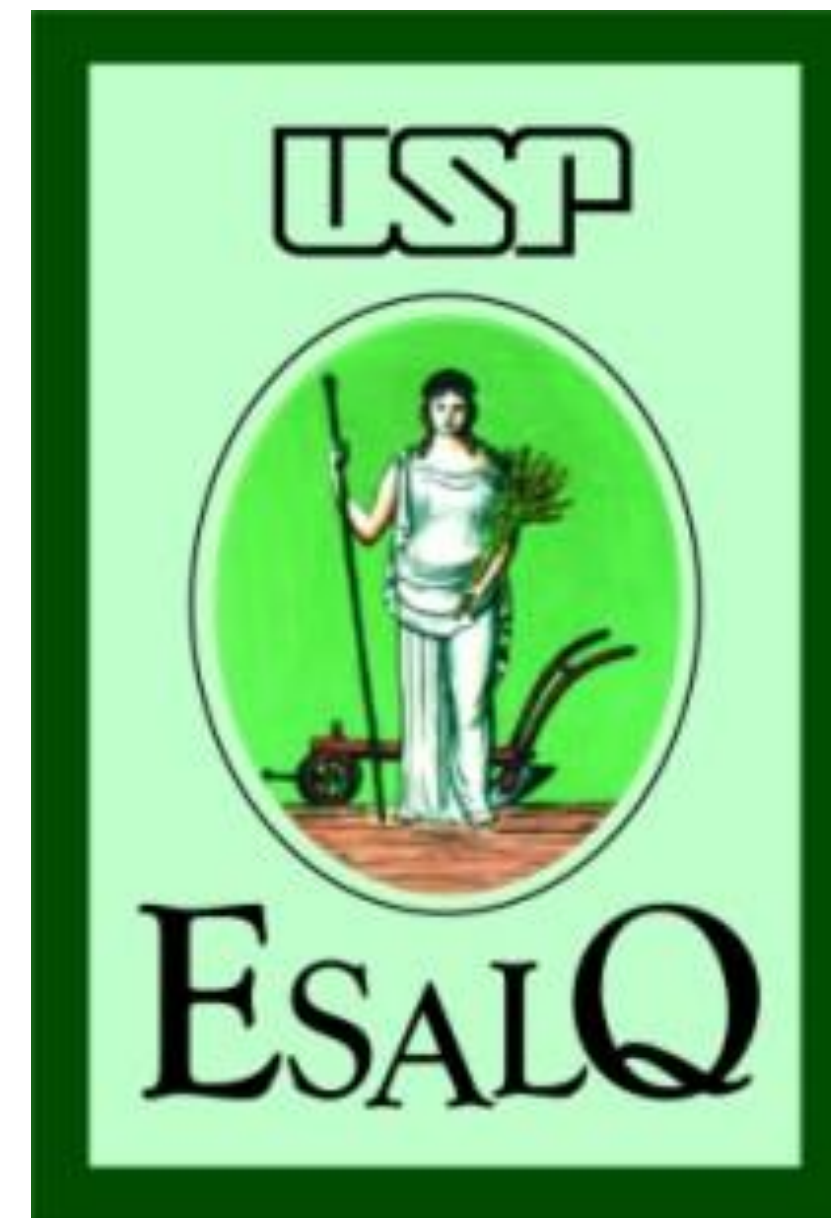
Analyzing the input-output efficiency of Water-Energy-Food Nexus in Brazil: a time-spatial approach

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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 repre-

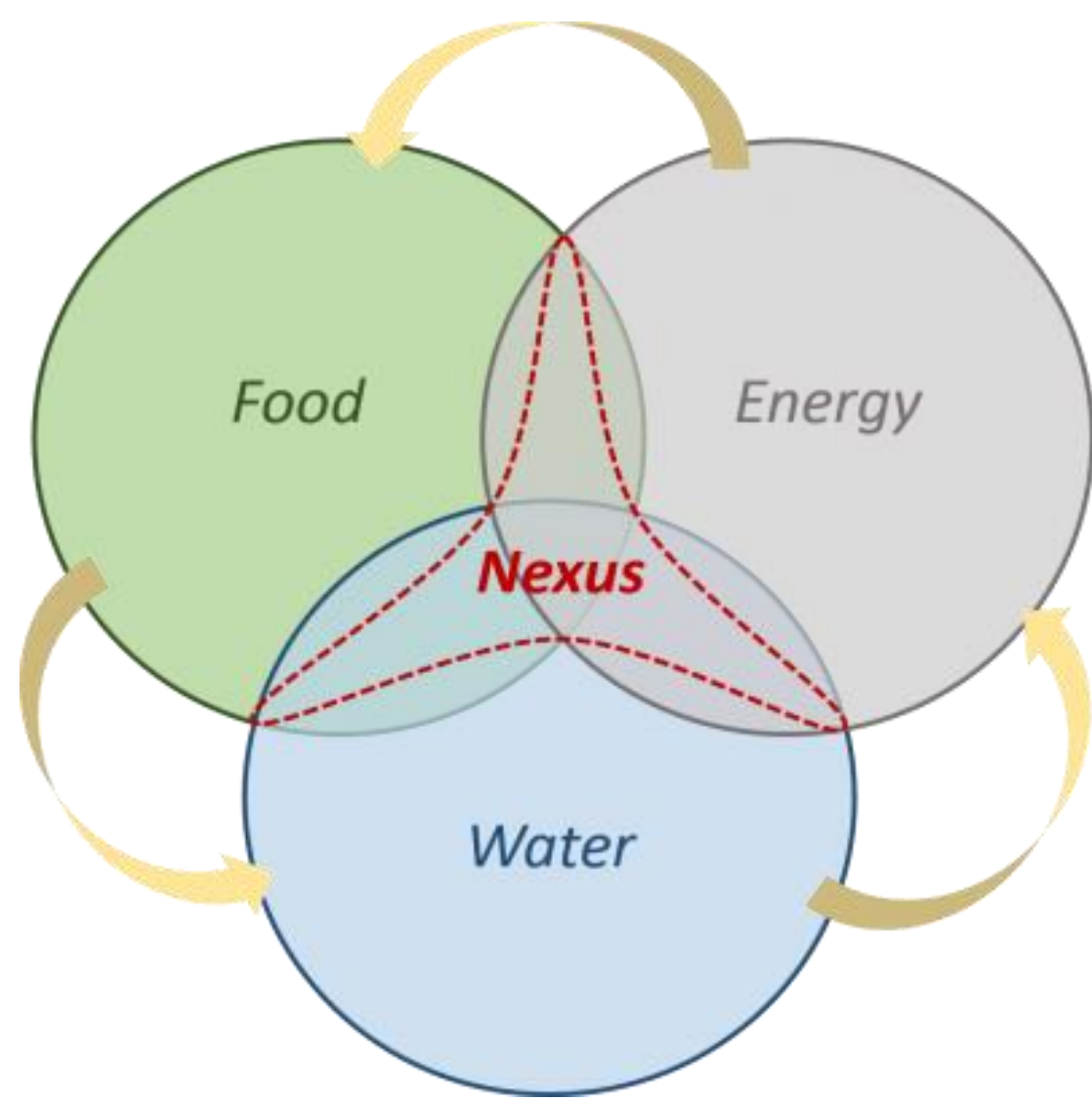


sent interconnections among variables and decision-making units. However, only few studies were able to deliver objective results to support policymakers to evaluate their actions, and to implement programs aiming to promote development with better use of limited resources. Our goal with this paper is 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.



W-E-F (Inputs)	Description (per capita/year)
WATER	Water use (m³)
	Water waste (production – consumption)
ENERGY	Electric energy consumption (MWh)
FOOD	Food waste (1,000 m³)
OTHER	Gas emission (tons of CO2e)
Output	Description
HDI-M	Municipal Human Development Index

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

B. Efficiency Analysis: Slack-Based Measure DEA

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

s.t.:

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

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

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

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

Source: Tone (2001)

- τ : Efficiency of *DMU0*
- t : Linearization variable
- S_i^- : Slack of *i*th input from *DMU0*
- S_j^+ : Slack of *j*th output from *DMU0*
- λ_k : Contribution of *k*th DMU to *DMU0*
- x_{ik} : *i*th input from *k*th *DMU*
- y_{jk} : *j*th output from *k*th *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	2008/09	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
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
	ES	22	24	27
Southeast	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 highest Malmquist Productive Index (MPI) evolution from 2009 to 2018, because the worsts positions did not maintained 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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