SPATIAL CONVERGENCE OF THE GROSS VALUE OF PRODUCTION OF FIREWOOD IN THE MESOREGIONS OF THE BRAZILIAN NORTHEAST[1]

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ABSTRACT – This paper analyzed the process of convergence in the gross value of wood production in mesoregions of Northeast Brazil, in the period of 1994 and 2013. The object of study was the Gross Value of Production (GVP) of firewood per km^2 of the mesoregions of the Northeast of Brazil. In the methodology the Absolute Convergence Model was applied and estimated through the classical model and spatial models. In the spatial approach we used the Spatial Autoregressive Model (SAR) and the Spatial Error Model (SEM). From the results obtained, the following conclusions were reached: The mesoregions of the Northeast of Brazil had an average fall of 3.94% a.a. of the GVP/km^2 of native wood for the period 1994 to 2013. Considering the classical linear regression model, convergence was verified and also the presence of spatial dependence for GVP/km^2 of firewood. In order to correct the spatial dependence, the SAR and SEM Models were adequate and according to Akaike's Information Criterion and used the rook matrix the SEM was configured the best model. This study showed the importance of the involvement of the spatial question in the models, either by the overlap of information of the GVP and in the development of public policies that positively affect the neighborhood.

Keywords: *Forest economics; Bioenergy; Spatial econometrics.*

CONVERGÊNCIA ESPACIAL DO VALOR BRUTO DE PRODUÇÃO DE LENHA NAS MESORREGIÕES DO NORDESTE BRASILEIRO

RESUMO – Este artigo analisou o processo de convergência no valor bruto de produção de lenha nas mesorregiões do Nordeste brasileiro, no período de 1994 e 2013. O objeto de estudo foi o Valor Bruto de Produção(VBP) de lenha por km^2 das mesorregiões do Nordeste brasileiro. Na metodologia aplicou-se o Modelo de Convergência absoluta e estimou por meio do modelo clássico e dos modelos espaciais. Na abordagem espacial foram utilizados o Modelo Autorregressivo Espacial (SAR) e o Modelo de Erro espacial (SEM). A partir dos resultados obtidos, chegaram-se as seguintes conclusões: As mesorregiões do Nordeste Brasileiro tiveram uma queda média de 3,94% a.a. do VBP/km^2 de lenha nativa, para o período de 1994 a 2013. Considerando o modelo clássico de regressão linear, a convergência foi verificada e também a presença dependência espacial para VBP/km^2 de lenha. Para corrigir a dependência espacial, os Modelos SAR e SEM foram adequados e de acordo Critério de Informação de Akaike e utilizado a matriz rook *o SEM se configurou o melhor modelo. Este estudo mostrou a importância do envolvimento da questão espacial nos modelos, seja pela sobreposição de informações do VBP e seja no desenvolvimento das políticas públicas que afetam positivamente a vizinhança.*

Palavras-Chave: *Economia florestal; Bioenergia; Econometria espacial.*

1. INTRODUCTION

Firewood is the oldest of all energy sources. The growth of cities spurred an increase in energy demand and promoted exploration in response to the limited regeneration capacity of the forest, which resulted in a short age of firewood in some regions (Uhlig, 2008).

In tropical regions, firewood costs little and requires no processing before use. In Brazil, 8.1% of the internal energy demand comes from forest resources (firewood and vegetable charcoal). Firewood is of considerable importance in the Brazilian energy matrix, and there has been a shortage of native firewood supply in some regions in Brazil. This may be due to decreasing vegetable exploration; the consequences are price increases and the need for reforestation. The most intensive use of firewood as an energy source is concentrated in the South, Southeast and Northeast of Brazil (IEA, 2006a,b, Brito and Deglise, 1991).

In Brazil, in 2013, the production of firewood reached 86.35 million m3. Of this total, 64.15% of the wood was from planted forests (silviculture) and 35.86% from native forest (vegetal extractivism). The main wood-producing regions for that year were the South (42.85%), the Northeast (21.82%), the Southeast (17.61%), the Midwest (10.84%) and the North (6.87%). Within these regions there is a discrepancy in proportion as to its origin, in the South and Southeast 90% of the supply of firewood comes from forestry, while more than 90% of the wood from the North and Northeast comes from the vegetal extractivism. The gross value of production (VBP) of wood from the Brazilian vegetable extractivism reached R$ 670.41 million and the Northeast corresponded to 43.80%, inserted in the caatinga biome (IBGE, 2018).

In the Northeast, firewood production matches demand. The producers decrease production when there are no buyers at suitable prices. The volume and the geographical distribution of firewood supply depend on buyers being willing to pay prices that interest the producers. This current supply pattern leads to the following risk: the concentration of production near consumer poles may promote degradation from the super-exploration of firewood (Riegelhaupt and Pareyn, 2010).

The Brazilian Northeast represents 18% of the national territory. It has about 2.5 million rural establishments, or 50% of Brazil. The semiarid Biome represents 10% of the Brazilian area and corresponds 39% of the rural population. Around 1.5 million rural settlements are located in the semiarid region, which 72% of them do not have definitive ownership of the land, reflecting the rate of deforestation and firewood production (Medeiros et al., 2012a). In the economic literature, there is an abundance of studies that test the convergence hypothesis of gross domestic product (GDP) or income, whether between nations or between regions of a country. The classic models of economic growth predict that if the free mobility condition of the production factors is satisfied, the per capita income of the different regions of a country will equalize. In neoclassic theory, this occurs because of the existence of decreasing marginal returns in the use of production factors (Ferreira, 1995).

These models consider that if the economies encompass similar technologies and preferences, poorer economies will have a higher growth rate for the GDP compared to richer economies. Therefore, the development distance between the economies will be reduced (Spohr and Freitas, 2011). To accommodate the need of using firewood with forest conservation, public policy must be aimed at effective management programs (Medeiros, 2010). It is important to understand the spatial distribution of firewood production in the Northeast, as well as how this production relates between regions, to identify a possible spatial dependence.

Spatial dependence or spatial autocorrelation is defined as the presence of positive or negative correlation of the distance between points and the similarity of the values measured for a certain variable to a degree greater than expected by chance. When the values are not statistically independent, they are said to be auto correlated. This violates one of the assumptions of traditional tests: the independence of the sample data (Legendre, 1993). Spatial econometric models incorporate the spatial dependence problem in the data, which improves the predicting power of the models. Spatial econometrics is a field in econometrics composed of techniques that address the inherent dependencies on space: spatial interrelations and spatial structure (Anselin, 2002). Spatial econometric results provide better information for decision support.

In Brazil, there are few papers dealing with the convergence of spatial income in the agrarian sciences. We highlight: Almeida et al. (2008) that dealt with the absolute convergence for the Brazilian average agricultural productivity, controlling the spatial effects and; (Aiher et al., 2016) analyzed the evolution of agricultural productivity in the microregions of Brazilian southern in the period of 1996 and 2006. However, there are no studies in the forestry sector that address the convergence of their production.

In view of the above, it is important to deal with the spatial effects of the convergence of the gross value of wood production, mainly in the Brazilian Northeast. Thus, this article analyzed the process of spatial convergence of the gross value of wood production in mesoregions of the Brazilian Northeast, in the period of 1994 and 2013.

2. MATERIALS AND METHODS

The data used were the Gross Value of Production (GVP) of firewood from vegetal extraction in the mesoregions of the Brazilian Northeast between 1994 and 2013.The data were acquired from the Automatic Recovery System (Sistema de Recuperação Automática – SIDRA) of the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística– IBGE). The values were corrected by the General Price Index – Internal Availability (Índice Geral de Preços - Disponibilidade Interna – IGP-DI) (2012 Base = 100). After normalization (monetary correction), the GVPs of each mesoregion were divided by the area (km^2) obtained from IBGE. This ensured that the area of the territory did not influence the results. Therefore, the index per area indicated the GVP/km^2 of the firewood in the extraction.

The Solow model (1956; 1957) was one of the precursors in this type of analysis. The convergence can be measured in two ways: σ-convergence and â-convergence. The first type refers to the dispersion values of a variable. The second type is related to the speed of convergence. The parameter β-convergence is classified as absolute or conditional. The absolute case occurs when the economies converge to the same steady state, whereas the conditional case occurs when the economies converge to their own steady states (Barro and Sala-I-Martin, 1991). The absolute convergence is realized performed by regression of the GVP growth rate in relation to the logarithm of the initial per capita income. The according with Almeida et al. (2008), the β-convergence model with spatial correction to the GVP of firewood in the mesoregions of the Northeast was expressed: $1n[(GVP_{2013}/km^2)/(GVP_{1994}/km^2)]= a+\rho W1n[(GVP_{2013}/km^2)/(GVP_{1994}/km^2)]+\beta 1n(GVP_{2013}/km^2)+\xi$, $\xi=\lambda W\xi+\varepsilon_i$, where, $1n[(GVP_{2013}/km^2)/(GVP_{1994}/km^2)]$= natural logarithm of the ratio of the GVP/km^2 of firewood in 2013 and in 1994; $1n(GVP_{1994}/km^2)$ = natural logarithm of the GVP/km^2 in the initial period; ξ = error term; $W1n[(GVP_{2013}/km^2)/(GVP_{1994}/km^2)]$ = spatial lag of the ratio of the GVP/km^2 of firewood in 2013 and in 1994; and ε = error term with zero mean and constant variance.

Note that ρ is the spatial lag coefficient, and because $\rho>0$, the presence of positive spatial autocorrelation is indicated. If β is negative, there is absolute convergence; i.e., the mesoregions with larger GVP of firewood have lower growth rates.

Spatial econometrics models address potential problems originating from the existence of spatial effects in the regression analysis. The spatial dependence, one of these effects, appears as a consequence of autocorrelation in explanatory (*Wx*) and dependent (*Wy*) variables or in the error term (*Wu*)(Schumacher, 2013). For the spatial dependency models, was realized according to Baumont (2004), the following:

1. Estimation of the classical model of linear regression by Method of Ordinary Least Squares (OLS);

In the classic linear regression model, the dependent variable was the natural logarithm of the GVP of firewood per area in the year 2013 in relation to the year 1994: $1n[(GVP_{2013}/km^2)/(GVP_{1994}/km^2)]$. The independent variable was the natural logarithm of the GVP of firewood per area in 1994: $1n(GVP_{1994}/km^2)$. To test the presence of spatial dependence, the following matrices were used: contiguity (“queen” and “rook” conventions) and number of nearest neighbors (1, 2, 3, 4 and 5 neighbors).

2. Testing of residuals of the spatial autocorrelation model, using Moran’s I for a set of matrices W;

Moran’s I test is a test used to investigate the presence of the spatial autocorrelation (spatial dependence) of the regression residuals. In Cliff and Ord (1973), Moran’s I test is expressed as:

$I = (n/S_0)e'We/e'e)$, where, $e = y X\beta^*$, where β^* is the ordinary least squares (OLS) estimator for β, and $S_0 = \Sigma_i \Sigma_j w_{ij}$, representing a normalization factor.

3. Selection of the spatial weight matrix that originated the largest value in Moran’s I test and that has statistical significance;

For the choice of the best spatial model, the following procedure was used (Almeida, 2012):

a. Estimation of the Classical Linear Regression Model (MCRL) model for OLS without any spatial lag

b. Testing of residuals by a diffuse spatial autocorrelation test with Moran's I

c. If there is no evidence of spatial autocorrelation, one must use the model estimated by OLS. If there is spatial dependence, the next step is taken;

d. Estimation of the spatial models;

Two types of spatial econometrics modeling were performed: Spatial Autoregressive Model (SAR) and Spatial Error Model (SEM). The maximum likelihood method was used. For Anselin et al. (2000), the SAR can be represented by: $y = \rho Wy + X\beta + \varepsilon$, where, y = matrix of dependent variables; Wy = spatially lagging dependent variable; ρ = intensity of interdependencies among sample observations of the endogenous variable; X = matrix of independent variables; β = estimated regression coefficients; and ε = the error term distributed with zero mean and constant variance.

For Almeida (2012), in the SAR model, the estimation of the parameters by the ordinary least squares (OLS) method can create a bias leading to inconsistency. The importance of the estimation by maximum likelihood is in the asymptotic properties: consistency, efficiency and normality (Arbia, 2006). Rêgo and Pena (2012) show that the SEM is expressed by: $y = X\beta + \varepsilon$, $\varepsilon = \lambda W\varepsilon + \xi$, where, $W\varepsilon$ = errors with spatial effect; ξ = refers to random errors with zero mean and variance σ^2; and λ = the autoregressive coefficient.

Note that the null hypothesis for the absence of autocorrelation is that $\lambda = 0$.

The model chosen was the one that satisfied two conditions: not having evidence of spatial autocorrelation in its residuals and presenting the lowest Akaike information criterion (AIC).

3. RESULTS

3.1. Analysis of the growth of the gross value of production of firewood

Table 1 presents the real GVP per area (GVP/km²) of firewood from extraction in the mesoregions in the Brazilian Northeast for the years of 1994 and 2013 (IGP-DI 2012 Base =100).

3.2. Convergence of the gross value of production of firewood

Table 2 presents the classic linear regression model via ordinary least squares (OLS) for the matrices of closest neighbors and of contiguity ("queen" and "rook").

Table 3 shows the estimation of the econometric SAR and SEM models.

4. DISCUSSION

4.1. Analysis of the growth of the gross value of production of firewood

During the analyzed period (Table 1), the Brazilian Northeast (1,554,291,744 km²) exhibited a decrease of 3.94% average annual (a.a.) in the GVP/km² of firewood. This reduce was largely verified in the states of Bahia, Maranhão and Ceará, and is associated with the substitution of firewood for other energy sources in the local production process, as well as the decrease in the supply of wood from forest suppression through expansion and occupation of urban and agricultural settlements.

However, some mesoregions showed a growth in firewood supply, mainly in the mesoregions of the States of Pernambuco (Sertão Pernambucano, São Francisco in Pernambuco), Paraíba (Borborema), Piauí (Southeastern Piauí) and Maranhão (Southern Maranhão). In Silva (2008-2009), this can be explained by the municipalities that compose the plaster complexin Chapada do Araripe, where the consumption of firewood reaches 30,000 m³ per month, resulting in deforestation of approximately 25 ha/day. The growing demand for firewood by the plaster complex justifies the tendency to use firewood because of its low cost. The use of firewood in the calcination process in the plaster pole of Araripe reduces the cost by approximately 80.44%.

Silva (2008-2009) showed the use of native firewood an excellent opportunity cost, which must be practiced in a sustainable manner, as opposed to the substitution of other energy sources, for example, natural gas, electricity, etc. According Table 1, in 1994, the largest GVP/km² of firewood in Northeast Brazil were in mesoregions of the States of Ceará (Metropolitan Fortaleza, Northern Maranhão) and Rio Grande do Norte (Center Rio Grande do Norte, Western Rio Grande do Norte). In 2013, they were in the mesoregions of the

Table 1 – The actual GVP per area (GVP/km²) of firewood from vegetal extraction (R$1,000.00) in the mesoregions of the Brazilian Northeast for the years of 1994 and 2013 (IGP-DI 2012 Base=100).
Tabela 1 – *Valor real bruto de produção da lenha per área (VBP/km²) do extrativismo vegetal (R$1.000,00), nas mesorregiões do Nordeste brasileiro, para os anos de 1994 e 2013 (IGP-DI Base 2012=100).*

States	Northeastern Mesoregions	Area (km²)	GVP/km²1994	GVP/km²2013	2013/1994 (% a.a.)
Maranhão	Northern Maranhão	52,491.41	0.5100	0.2544	-3.59
	Western Maranhão	86,873.69	0.1137	0.0240	-7.86
	Center Maranhão	54,179.28	0.1243	0.1120	-0.55
	Eastern Maranhão	70,693.12	0.7731	0.2291	-6.20
	Southern Maranhão	67,699.45	0.1378	0.1529	0.55
Piauí	Northern Piauí	22,186.49	0.1640	0.0748	-4.05
	Center Northern Piauí	55,254.48	0.0844	0.0554	-2.19
	Southwestern Piauí	128,008.00	0.0271	0.0386	1.88
	Southeastern Piauí	46,162.96	0.0688	0.1375	3.71
Ceará	Northwestern Ceará	34,527.15	0.4096	0.3170	-1.34
	Northern Ceará	21,063.28	1.3622	0.3737	-6.58
	Metropolitan Fortaleza	3,767.71	2.9228	0.0447	-19.75
	Sertões in Ceará	46,250.89	0.5969	0.2120	-5.30
	Jaguaribe	18,440.96	0.6650	0.1595	-7.24
	Mid-southern Ceará	9,944.19	0.9556	0.2045	-7.79
	Southern Ceará	14,892.13	0.8627	0.4101	-3.84
Rio Grande do Norte	Agreste in Rio Grande do Norte	9,385.437	0.3398	0.2696	-1.21
	Center Rio Grande do Norte	15,810.34	1.3220	0.3806	-6.34
	Eastern Rio Grande do Norte	6,440.314	1.0674	0.0219	-18.50
	Western Rio Grande do Norte	21,175.04	1.2039	0.4596	-4.94
Paraíba	Agreste in Paraíba	12,931.05	0.2299	0.0887	-4.89
	Borborema	15,576.81	0.1590	0.2038	1.32
	Mata in Paraíba	5,232.70	0.0316	0.0094	-6.18
	Sertão in Paraíba	22,729.19	0.2910	0.2085	-1.74
Pernambuco	Agreste in Pernambuco	24,549.08	0.3321	0.0887	-6.71
	Mata in Pernambuco	8,402.31	0.0820	0.0262	-5.83
	Metropolitan Recife	2,787.47	-	-	-
	São Francisco in Pernambuco	24,457.52	0.2159	0.4093	3.42
	Sertão in Pernambuco	37,952.75	0.1697	0.5799	6.68
Alagoas	Agreste in Alagoas	5,764.09	0.0876	0.0101	-10.75
	Eastern Alagoas	13,243.58	0.1796	0.0080	-15.10
	Sertão in Alagoas	8,767.33	0.3477	0.1221	-5.36
Sergipe	Agreste in Sergipe	5,902.86	0.1966	0.0370	-8.42
	Eastern Sergipe	8,700.05	0.4805	0.0140	-16.98
	Sertão in Sergipe	7,315.57	0.1342	0.0454	-5.54
Bahia	CenterNorthern Bahia	82,110.40	0.4477	0.4338	-0.17
	Center Southern Bahia	127,914.90	0.5008	0.2506	-3.58
	Far Western Bahia	117,438.00	0.1777	0.0701	-4.78
	Metropolitan Salvador	11,282.61	0.5896	0.1306	-7.63
	Northeastern Bahia	56,461.91	0.3778	0.1372	-5.19
	Southern Bahia	54,705.69	0.7915	0.0605	-12.66
	Vale São Franciscano da Bahia	114,819.6	0.5261	0.1759	-5.60

Source: Prepared by the authors based on data from IBGE.

States of Ceará (Southern Ceará), Pernambuco (Sertão Pernambucano), Rio Grande do Norte (Western Rio Grande do Norte) and Bahia (Center Northern Bahia).

Silveira (2007) showed that these regions are related to the production of ceramics, given that, together with Piauí and Maranhão, they stand out as ceramic producers in the Northeast.

The GVP/km² retractions of native firewood from the Northeast are associated with its exacerbated consumption, performed during previous periods, as

Table 2 – Classic linear regression model via ordinary least squares for the GVP/km² of firewood in the Brazilian Northeastern mesoregions during 1994-2013.
Tabela 2 – *Modelo clássico de regressão linear via mínimos quadrados ordinários para o VBP/km² de lenha das mesorregiões do Nordeste brasileiro, no período de 1994-2013.*

Spatial Weights Matrix	Moran's I	
	Test I	Residual P-Value
1 neighbor	1.2800	0.1040
2 neighbors	1.9948	0.0310
3 neighbors	2.2840	0.0190
4 neighbors	2.3347	0.0170
5 neighbors	2.7265	0.0270
Queen	2.7303	0.0100
Rook	2.7617	0.0080

Source: Prepared by the authors based on results obtained with the software Geoda.

Table3 – Spatial econometric SAR and SEM models for the contiguity matrices of types *queen* and *rook*, considering the GVP/km² of firewood for the Brazilian Northeastern mesoregions, during 1994-2013.
Tabela 3 – *Modelos econométricos espaciais SAR e SEM para as matrizes de contiguidade tipo queen e rook, considerando o VBP/km² de lenha para as mesorregiões do Nordeste brasileiro, no período de 1994-2013.*

	SAR Model		**SEM Model**	
	Queen	*Rook*	*Queen*	*Rook*
AIC	122.774	122.932	121.065	120.893
Residual p-value	0.2120	0.2380	0.3130	0.3020
Coefficient of the constant	-1.1226	-1.1660	-1.6101	-1.6496
Coefficient of ln(GVP_{1994}/km²)	-0.4179	-0.4404	-0.46107	-0.4911
P-value of the constant	0.0001	0.0001	0.0000	0.0000
P-value of the ln (GVP_{1994}/km²)	0.0041	0.0026	0.0036	0.0018
Standard error of the constant	0.2844	0.2867	0.3043	0.3027
Standard error of ln (GVP_{1994}/km²)	0.1457	0.1465	0.1582	0.1570

Source: Prepared by the authors based on results obtained with the software Geoda.

energy source for ceramics, lime kilns, cheese factories, bakeries, flour mills, brick kilns, coal plants, manufacturing units of homemade cookies, confectioneries, stills, mills, mining, roasting industries, textile industries, margarine and soap industries, etc. Thus, there was an uncontrolled use of native vegetation due to the lack of a sustainable management plan for rural establishments and environmental agencies oversight, generating problems of market equilibrium; Besides favoring the phenomenon of desertification in the Brazilian semiarid biome (Riegelhaupt and Pareyn, 2010; Medeiros et al., 2012a,b)

The growth of GVP/km² of native wood in northeastern Brazilian mesoregions, mainly regarding the Sertão in Pernambuco, is related to the Local Productive Arrangement (LPA) of the Polo Gesseiro do Araripe, which corresponds to 94% of the national production of plaster. In 2008, the plaster production was approximately 4.2 million tons, which demanded approximately 2.94 million stere meters (stm) of firewood. Together with other productive sectors, the demand for firewood as an energy source exceeded 4 million stm (Silva, 2008-2009).

These poles of development with their respective LPA, linked by the demand for native wood, contribute to reduce the inequalities of wood production according to their availability of forest exploration.

For the mesoregions of the State of Sergipe, the drop in the annual average growth of the GVP/km² of firewood can be explained by the absence of plantations of forest species with rapid growth and lack of licensing projects at environmental agencies for management of the caatinga. In addition, the demand for firewood, mainly from the ceramics sector, promotes an imbalance between supply and demand of this resource in the State of Sergipe (Aragão et al., 2008).

4.2. Convergence of the gross value of production of firewood

According Table 2 and equation 6, it was observed that the coefficient of the constant, as well as the independent variable ln (GVP_{1994}/km²), presented values with negative signs. The p-values of the independent variable were significant at 5%.

$$y = -1{,}5712 - 0{,}4543(GVP_{1994}/km^2) + \varepsilon$$

Despite the observation of divergence in a large number of the mesoregions, the negative sign of the independent variable indicates absolute convergence. Some mesoregions with low values of GVP/km² of firewood are growing at rates higher than mesoregions with higher GVPs/km².

The global convergence of the GVP/km² of firewood is associated with the availability of vegetation, the intensification of forest exploitation and the increase of agricultural and urban expansion. The mesoregions with the highest values of GVP/km² of firewood were highly explored, reducing the availability of these forest resources and decreasing firewood production. With the development of sustainable management practices for the forest in the Caatinga, mesoregions in the states of Pernambuco, Paraíba and Piauí were found promising for firewood production. Some municipalities in these mesoregions present a strong demand for firewood.

This sustainable production of firewood in the semiarid region will attenuate the inequalities of the regional production that infers in the convergence of production, according to the model presented (Table 2 and equation 6). The public policy guidelines have been providing affirmative actions for the development of sectors that use firewood with energy source. One of those is the program to combat desertification, linked to the Ministry of Environment, which uses strategies for the sustainable use of biodiversity of the caatinga through. One example is the Sustainable Industrial Production Center (CEPIS), which focuses on optimizing processes, energy efficiency and promoting economic and environmental sustainability for industries in the Northeast region, making it easier to enter the world market. They train, mainly, ceramic companies and rural proprietors to the economic efficiency of the forest resources through the management of industrial processes and the plans of forest management in the caatinga.

The residual test for the model (Residual P-value) indicated the presence of spatial autocorrelation (Table 2). Therefore, the GVP/km² of firewood of a certain mesoregion is associated with others mesoregion(s). The spatial dependence observed for the GVP/km² of firewood is connected to the differences of availability of the vegetation among the mesoregions. The political-administrative geographical boundaries are different from the native vegetation areas, and the forest exploration of an area may end up being recorded in another area, which creates measurement errors. This result suggests that the classic linear regression model is not appropriate for econometric estimations, which demand models with spatial correlations.

In this context, adopted public policies can produce spatial overflow effects on wood production, not only in the target area of the policy itself, but also in its neighborhood. This shows the relevance of estimation strategies that consider the spatial correction of the model.

The Moran's I test by the Baumont (2004) criterion showed that the highest value came from the rook contiguity matrix (2.7617) and queen type (2.7303), respectively. Thus, for the estimation strategies of the spatial models, these two matrices were used.

According to Table 3, the SAR model, considering the queen weights matrix, it was verified that both the coefficient of the constant and of the independent variable $\ln(GVP_{1994}/km^2)$ had negative signs and statistically significant at 5%. The result of the explanatory variable indicates that mesoregions of the Brazilian northeast with lower GVP/km² of firewood are growing at higher rates than the mesoregions with higher GVP/km². In other words, there is a tendency for convergence GVP/km² of firewood.

The SAR model solved the spatial dependence problem, since the value obtained for the residual test (residual p-value) was not significant for rook and queen spatial weight matrices. The coefficient of the explanatory variable was negative and statistically significant. This indicates the occurrence of convergence GVP/km² of firewood in the mesoregions of Northeast Brazil.

In the SEM model, considering the queen matrix, the values of the coefficients of the constant and $\ln(GVP_{1994}/km^2)$ variables were -1.610105 and -0.4610661, respectively and were statistically significant. Compared to the SAR model, the SEM model also exhibited convergence. The p-value for the variables was significant at 5%: constant (0.00000) and $\ln(GVP_{1994})$(0.00356). The residual p-value for the SEM model did not indicate statistical significance for the spatial dependence and was higher (0.313000) than the SAR model of the queen matrix. The AIC value (121.065) was lower than that observed in the SAR (122.774) model; therefore, the SEM model was observed to be better than the SAR model.

The SEM model estimated for the contiguity matrix of type rook converged with the following coefficients for the variables: constant (-1.649592) and $\ln(GVP_{1994}/km^2)$ (-0.4910877). The p-values of the constant and dependent variables indicated statistical significance at 5%: 0.00000 and 0.00177, respectively.

The strategy used to estimate spatial models solved the problem of spatial dependence because the value obtained in the residual test (residual p-value) was not significant for the presence of spatial autocorrelation. Despite the SAR model (considering the rook matrix) also solving the spatial dependence problem, the SEM model exhibited a higher residual p-value (0.302). Also noteworthy is that the value of the AIC (120.893) was smaller than that verified by the SAR model (122.932). Thus, the SEM model is better than the SAR model.

5.CONCLUSION

From the analyses performed, the following conclusions were determined:

- The mesoregions of the Brazilian Northeast had an average fall of 3.94% a.a. of the (GVP / km_2)of native firewood, for the period 1994 to 2013. The main mesoregions of the Northeast with the highest average annual growth of firewood and (GVP / Km_2) were: Southern Maranhão, Southwestern Piauí, Borborema, São Francisco in Pernambuco and Sertão in Pernambuco;

- Among the matrices analyzed, queen and rook showed higher values for Moran's I Test, and the SAR and SEM models solved the problem of spatial dependence. According to AIC the SEM Model was better;

- This study showed the importance of spatial involvement in the econometric models of the effects of space overflows, that is, by overlapping information from the GVP and in the development of public policies that positively affect the neighborhood;

- The lack of information or non-existence of the firewood VBP in the municipalities of the Brazilian Northeast impairs the accuracy of the results obtained, not providing elements for a better orientation in public policies;

- The limitation of this study (absolute convergence) is to use the data itself to explain convergence. For future work, other variables and methods should be used to consider regional differences;

- The research should be continued through the methodology of conditional convergence, cross section data and panel data. These methods can also consider and correct spatial heterogeneity due to differences in geographic units in order to obtain more efficient results.

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7.REFERENCES

Aiher AP, Oliveira RA, Carmo ASS, Stege AL. Convergência da produtividade agropecuária do Sul do Brasil: uma análise espacial. Revista de Economia e Sociologia Rural [online]. 2016;54(3):517-36.

Almeida E. Econometria espacial aplicada. Campinas: Alínea; 2012.

Almeida ES, Perobelli FS, Ferreira PGC. Existe convergência espacial da produtividade agrícola no Brasil? Revista de Economia e Sociologia Rural. 2008;46(1):31-52.

Anselin L. Under the hood: issues in the specification and interpretation of spatial regression models (forthcoming: Agricultural Economics). Agricultural Economics. 2002;27:247-67.

Anselin L, Varga A, Acs Z. Geographical spillovers and university research: A Spatial econometric perspective. Growth and Change. 2000;31(4):501-15.

Aragão FM, Gomes LJ, Nogueira M, Ribeiro GT. Caracterização do consumo de lenha pela atividade cerâmica, nos municípios de Itabaiana, Itabaianinha e Umbaúba-SE. Revista Científica Eletrônica de Engenharia Florestal. 2008;7(12). http://faef.revista.inf.br/imagens_arquivos/arquivos_destaque/QcUvEVGcI2l73E0_2013-4-29-9-47-43.pdf

Arbia G. Spatial econometrics: statistical foundations and applications to regional convergence. London: Springer; 2006. (Advances in Spatial Sciences Series)

Barro R, Sala-I-Martin X. Convergence across states and regions. Brookings Papers on Economic Activity. 1991;1:107-82.

Baumont C. Spatial effects in housing price models: do house prices capitalize urban development policies in the aglomeration of Dijon

(1999)? Université de Bourgogne, 2004. [não publicado]. http://leg.u-bourgogne.fr/images/stories/pdf/doc_trav2004/e2004-04.pdf

Brito JO, Deglise X. States and potential of using wood for energy in Brazil. Revue Forestière Française. 1991(6):175-79.

Cliff A, Ord JK. Spatial autocorrelation. London: Pion; 1973.

Ferreira AHB. O debate sobre a convergência de rendas per capita. Nova Economia. 1995;5(2):1-29. http://revistas.face.ufmg.br/index.php/novaeconomia/article/view/2280/0

Instituto Brasileiro de Geografia e Estatística - IBGE. Produção da Extração Vegetal e da Silvicultura - PEVS. Sistema IBGE de Recuperação Automática - SIDRA. 2018. Disponível em: http://www.sidra.ibge.gov.br.

International Energy Agency – IEA. Energy balances of non-OECD countries 2003 – 2004. Paris: OECD; 2006a.

International Energy Agency – IEA. Energy balances of OECD countries 2003 – 2004. Paris: OECD; 2006b.

Legendre P. Spatial autocorrelation: trouble or new paradigm? Ecology. 1993;74(6):1659-73.

Medeiros PM. Uso de produtos madeireiros para ins domésticos em uma área de Floresta Atlântica no Nordeste Brasileiro [dissertação]. Recife: Universidade Federal Rural de Pernambuco, 2010.

Medeiros LRA, Ismael LL, Brasiliano LN, Schmidt Filho R. Desertificação na Paraíba: Diagnóstico e perspectivas. Revista de Agroecologia e Desenvolvimento Sustentável. 2012b;7(1):239-48.

Medeiros SS, Cavalcante AMB, Marin AMP, Tinôco LBM, Salcedo IH, Pinto TF. Sinopse do Censo Demográfico para o Semiárido Brasileiro. Campina Grande: INSA; 2012a.

Morais IRD. Seridó norte-riograndense: uma geografia da resistência. Caicó: Edição do autor; 2004.

Rêgo CV, Pena MG. Análises dos modelos de regressão espacial SAR, SEM e SAC [monografia]. Brasília, DF: Universidade de Brasília; 2012.

Riegelhaupt EM, Pareyn FGC. A questão energética. In: Gariglio MA, Sampaio EVSB, Cestaro LA, Kageyama PY. organizadores. Uso sustentável e conservação dos recursos florestais da caatinga. Brasília, DF: Serviço Florestal Brasileiro; 2010. p.65-75.

Schumacher G. Produção de leite no Rio Grande do Sul: A distribuição espacial e a relação de dependência entre os municípios [dissertação]. Santa Maria: Universidade Federal de Santa Maria; 2013.

Silva JAA. Potencialidades de florestas energéticas de Eucalyptus no Polo Gesseiro do Araripe – Pernambuco. Anais da Academia Pernambucana de Ciência Agronômica. 2008-2009;5-6:301-19.

Silveira MS. Arranjo produtivo local: o estudo de caso da cerâmica vermelha de Russas [monografia]. Fortaleza: Universidade Federal do Ceará;, 2007.

Solow RM. A Contribution to the theory of economic growth. Quaterly Journal of Economics. 1956;70:65-94.

Solow RM. Technical change and the aggregate production function. The Review of Economics and Statistics. 1957;39(3):312-20

Spohr G, Freitas CA. Teste da Convergência do PIB per capita da agropecuária no Brasil entre 1980 e 2004. Revista de Economia e Sociologia Rural. 2011;49(2):341-68.

Uhlig A. Lenha e carvão vegetal no Brasil: balanço oferta-demanda e métodos para estimação do consumo [tese]. São Paulo: Universidade de São Paulo; 2008.

ERRATA

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