ECONOMIC GROWTH AND ENERGY CONSUMPTION: A SUR REGRESSION MODEL APPLICATION IN BRAZIL FOR SEVERAL SOURCES OF FUEL

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Grupo de Pesquisa: 6 – Agricultura, Meio-Ambiente e Desenvolvimento Solidário

RESUMO

Apesar de uma série argumentos teóricos e evidências empíricas demonstrarem que a partir de certos níveis de renda ocorre a chamada EKC (*Environmental Kuznets Curve*), i.e., uma relação em "U" invertido entre renda e degradação ambiental (ou consumo dos recursos naturais) estudos aplicados demonstraram que para o caso do consumo de energia no Brasil, esta relação não se verifica. A melhoria na qualidade ambiental poderia, no entanto, estar ocorrendo pela troca de uma matriz energética mais intensiva na emissão de poluentes por uma menos agressiva. Para verificar este efeito foram estimadas várias EKC's para diferentes tipos de fonte primárias de energia (petróleo, álcool de cana-de-açúcar, gás natural, carvão mineral e vegetal, hidroeletricidade residencial e industrial e lenha). Como a princípio as demandas são correlacionadas entre si, foi utilizado um modelo de regressão do tipo SUR (*Seemingly Unrelated Regressions*). O resultado obtido confirma a hipótese de que as funções são correlacionadas contemporaneamente e que o nível de consumo da maioria das fontes de energia é crescente em função da renda (algumas com elasticidade também crescente). Outros resultados extraídos indicam que a participação das fontes renováveis tende a decair ao longo do processo de crescimento econômico; e, há um aumento exponencial nas emissões de carbono no longo-prazo (tanto originário de fontes renováveis quanto não-renováveis).

Palavras-chaves: EKC (*Environmental Kuznets Curve*), Consumo de Energia, Emissão de Carbono, Crescimento Econômico, SUR.

ABSTRACT

Although some theoretical and empirical evidences show that under some level of income the relationship between income and the use of natural resources and environmental quality is inverted U-shaped (the well know EKC-Environmental Kuznets Curve), applied studies have shown that for the case of per capita energy consumption in Brazil the EKC doesn't applies. However, an improvement on environmental quality would be occurring be the substitution of the energy matrix to another one less intensive on pollutants. Objecting the extraction of this effect it had been done the estimation of several EKC's for different sources of fuel (petroleum, sugar-cane alcohol, natural gas, mineral and vegetal coal, residential and industrial hydroelectricity and wood). Once those sources of energy demand are, by substitution, correlated, it had been used the econometrical technique of the regression by SUR (Seemingly Unrelated Regressors). The final result had shown what was expected: the different energy sources are contemporaneously correlated and they are in most part positively correlated with income, actually some of then have increasing elasticity on income. Some simulations done indicates that the percent participation of the renewable sources of energy is decreasing along economic growth; and, the carbon emissions is exponential increasing on long-run (either renewable and non-renewable).

Key-words: EKC (Environmental Kuznets Curve), Energy Consumption, Carbon Emissions, Economiv Growth, SUR model.

1 INTRODUCTION, JUSTIFICATION AND OBJECTIVES

In recent years, Environmental Kuznets Curve (EKC) has been tested quite extensively in several situations. Theoretical and empirical studies (such as SHAFIK & BANDYOPHADYAY, 1992; GROSSMAN & KRUEGER, 1993; WORLD BANK, 1992, and SELDEN & SONG, 1994) has shown that the relationship between income and the use of natural resources (or, alternatively, the level of environmental quality) has an inverted U-shaped curve (Fig. 1).

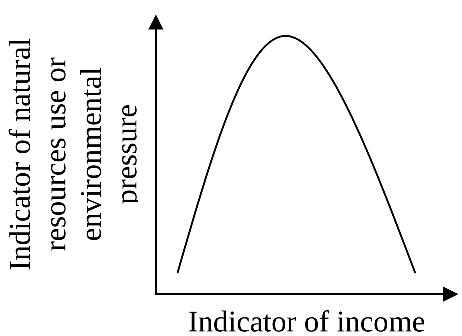

Figure 1. The Environmental Kuznets Curve.

According to them, the inverted "U-shaped" relationship results from the interaction between several effects, among which the most important are: consumer demand for environmental quality, des-industrialization and the development of new and more efficient technologies.

Other studies show that for some cases, the inverted U-shaped relationship does not seem to exist (SHAFIK & BANDYOPHADYAY, 1992; SHAFIK, 1994; GROSSMAN & KRUEGER, 1995). In Brazil, past data does not support the EKC hypotheses that income growth will reduce energy consumption in the foreseeable future (KAMOGAWA, 2004). According to the study, the relationship between these variables is best adjusted by a cubic (without turning-points) increasing model (Fig. 2).

Unfortunately, higher energy consumption results in undesirable effects such as: i) necessity to expand the energy supply system to meet increased demand (which requires large investments, including by the government) and, as a consequence, faster depletion of reserves; and, ii) larger amount of negative externalities, affecting not only the human health but also all the environment (KAMOGAWA, 2004).

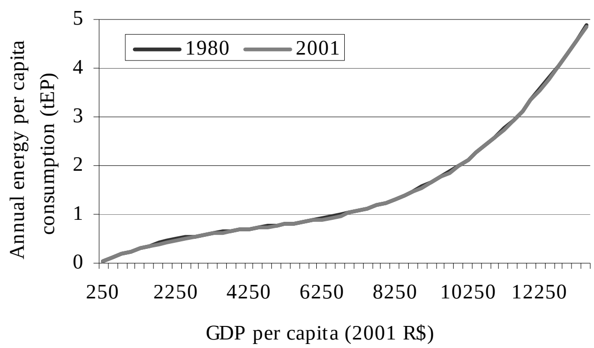

Figure 2. Estimated relationship between per capita income (on 2001 R$) and per capita energy consumption (tEP/person) on Brazil, 1970-2001.
Source: KAMOGAWA (2004)

Technology may help solve the last problems in two ways. First, by improving the efficiency in which traditional sources of energy are used. Second, facilitating the process of substitution from sources that generate large amount of negative externalities (such as the petroleum, mineral coal and natural gas) to other sources that have smaller impacts (vegetal coal, sugar-cane complex and hydroelectricity).

To analyse the dynamics of economic growth on these issues, this study propose the estimation of one EKC’s for each sources of energy (petroleum, mineral coal, charcoal, natural gas, sugar-cane alcohol, wood and hydroelectricity) using SUR (Seemingly Unrelated Regressions) method (GRIFFITHS, 1993). The regressions are used to test the presence of contemporaneous correlation and evidence of a turning-point to any of the sources of fuel (preferably the sources intensive on externalities) and for carbon emissions.

2 METHODOLOGY AND MODEL

In order to estimate the effects of energy consumption on environmental quality, EKC’s are estimated for different sources of energy. Individual regressions for each fuel source are estimated by OLS (Ordinary Least Squares), according to (eq. 1):

$$\ln ENE_{ti} = \beta_1 \left(\ln Y_t\right) + \beta_2 \left(\ln Y_t\right)^2 + \beta_3 \left(\ln P_{ti}\right) + \varepsilon_{ti} \quad \text{(eq. 1)}$$

Where:

β_j are the j parameters to be estimated;

$\ln ENE_{ti}$ is the natural log of annual per capita consumption of the energy source i at year t;

$\ln Y_t$ is the natural log of per capita GDP (on 2004 R$) at year t;

$\ln P_{ti}$ is the natural log of the price of the energy source i (on 2004 R$/tEP) at year t; and,

ε_{ti} is the error in energy source equation i at year t.

This approach results in proper estimates if residuals are not contemporaneously correlated. That is, the correlation between cross-equation errors must by zero (eq. 2):

$$E\begin{bmatrix} e_1'e_1 & \cdots & e_1'e_j \\ \vdots & \ddots & \vdots \\ e_i'e_1 & \cdots & e_i'e_j \end{bmatrix} = \begin{bmatrix} e_1'e_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & e_i'e_j \end{bmatrix}; \text{ where } e_i'e_i = 0 \text{ for } i \neq j. \qquad \text{(eq. 2)}$$

However, it is expected that consumption of different fuels have covariance matrix of error with contemporaneous correlation, in the spirit of Zellner's SUR regression model (GRIFFITHS, 1993). In this case, parameters can be properly estimated by:

$$\begin{bmatrix} \ln ENE_1 \\ \ln ENE_2 \\ \vdots \\ \ln ENE_i \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \cdots & 0 \\ 0 & X_2 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & X_i \end{bmatrix} \begin{bmatrix} \beta_{11} & \beta_{21} & \beta_{31} \\ \beta_{12} & \beta_{22} & \beta_{32} \\ \vdots & \vdots & \vdots \\ \beta_{1i} & \beta_{2i} & \beta_{3i} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_i \end{bmatrix} \qquad \text{(eq. 3)}$$

Where:

$$X_i = \begin{bmatrix} \ln Y_t & (\ln Y_t)^2 & \ln P_{it} \end{bmatrix}$$

The sources of energy selected (the cross-section unities) are the most relevant for the Brazilian energy matrix: petroleum, mineral coal, charcoal, natural gas, sugar-cane alcohol, wood and residential and industrial hydroelectricity.

Functional forms (linear of quadratic) are tested by a goodness-of-fit test[1] (NETER, 2001).

The independence between the error terms from different equations is tested using a Multivariate Independent (MI) statistics which is able to handle disturbances across different regressions with serial correlation (TSAY, 2004). The MI statistics follow a χ^2 distribution with $p(p-1)/2$ degrees of freedom, just as Breush-Pagan LM test (TSAY, 2004). This test is given by (eq. 4):

$$MI \equiv \hat{\Lambda}'\hat{\Omega}^{\wedge-1}\hat{\Lambda} \qquad (4)$$

Where:

[1] The best fit according to some appropriate statistics (F-statistics, student-t, R^2) (NETER, 2001).

$$\hat{\Lambda} \equiv T^{-1/2} \sum_{t=1}^{T} \hat{Z}_t$$

$$\hat{Z}_t' = \left(\hat{Z}_{12,t} \quad \cdots \quad \hat{Z}_{1p,t} \quad \cdots \quad \hat{Z}_{(p-1)p,t} \right)$$

$$\hat{\Omega} \equiv \begin{bmatrix} \hat{\Omega}_{12} & 0 & \cdots & 0 \\ 0 & \hat{\Omega}_{13} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \hat{\Omega}_{(p-1)p} \end{bmatrix}$$

Such that:

$$\hat{\Omega}_{ij} = \sum_{h=-T+1}^{T-1} C_{i,h} C_{j,h}; \text{ and,}$$

$$C_{i,h} = T^{-1} \sum_{t(h)} e_{i,t} e_{i,t+h}, \; C_{j,h} = T^{-1} \sum_{t(h)} e_{j,t} e_{j,t+h}.$$

Energy consumption and their prices, by source of fuel, were obtained from Brazilian Energy Matrix - *BEN* (*Balanço Energético Nacional*) between 1987 and 2002 (MME, 2004). Energy consumption are expressed in terms of tEP[2] (tones of equivalent of petroleum) per person and prices by R$/tEP/year. Per capita GDP was obtained from IPEADATA (IPEADATA, 2005). All monetary values were deflated by IGP/DI (real values of 2004).

Estimates of carbon emissions were obtained using the conversion factor from Brazilian Ministry of Sciency and Tecnology (MCT, 2000) (Appendix). They are expressed in terms of Gg of CO_2 per year.

4 REGRESSION RESULTS

Goodness-of-fit criterion rejects the hypothesis that energy consumption and GDP has a quadratic relationship for two of the eight sources considered (vegetal coal and wood). The same test rejects that prices affect energy consumption for six sources. Only natural gas and charcoal seem to be sensitive to price variation.

Parameters are re-estimated after variables are re-arranged (exclusion those that are not significant). The results are presented in (Tab. 1) below.

Table 1. Econometrical results of the SUR regression model by OLS for the dependent variable energy consumption by source of fuel[a].

Source	$\ln Y$	$(\ln Y)^2$	$\ln P$	R^2	*A-C*	χ^2
Petroleum	-1.902	0.199	-	0.994	7.377	2968.00
	(0.000)	(0.000)			(0.006)	(0.000)
Alcohol	-1.122	0.099	-	0.998	1.067	12160.26
	(0.005)	(0.024)			(0.302)	(0.000)
Natural Gas	-3.493	0.381	-0.896	0.997	3.268	5844.20
	(0.001)	(0.001)	(0.000)		(0.071)	(0.000)

[2] 1 tEP= 1 toe (tones of oil equivalent).

Vegetal Coal	-0.378	-	-0.369	0.999	0.021	16432.53
	(0.000)		(0.001)		(0.885)	(0.000)
Mineral Coal	-1.237	0.101	-	0.999	0.345	239798.26
	(0.000)	(0.000)			(0.557)	(0.000)
Residential hydroelectricity	-3.016	0.288	-	0.998	66.837	10797.39
	(0.000)	(0.000)			(0.000)	(0.000)
Industrial hydroelectricity	-0.884	0.063	-	0.999	0.527	106828.16
	(0.000)	(0.002)			(0.468)	(0.000)
Wood	-0.203	-	-	0.987	152.187	1294.74
	(0.000)				(0.000)	(0.000)
MI test	1127.000					
	(0.000)					

[a] The null hypothesis probability is under parenthesis.

Autocorrelation has been found in three out of the eight sources (petroleum, residential hydroelectricity and wood) (Tab. 1). Contemporaneous correlation among the cross-section units is found by MI Tsay statistics.

Since serial correlation was found in some of the equations, Prais-Wisten transformation was applied accordingly. After this adjustment, parameters were estimated by GLS (General Least Squares) using the Zellner´s SUR model. The final estimates are presented below (Tab. 2).

Source	$\ln Y$	$(\ln Y)^2$	$\ln P$	R^2	χ^2
Petroleum	-1.306	0.133	-	0.982	8618.63
	(0.000)	(0.000)			(0.000)
Alcohol	-1.122	0.099	-	0.998	12160.26
	(0.005)	(0.024)			(0.000)
Natural Gas	-3.493	0.381	-0.896	0.997	5844.20
	(0.001)	(0.001)	(0.000)		(0.000)
Vegetal Coal	-0.378	-	-0.373	0.999	18620.89
	(0.000)		(0.001)		(0.000)
Mineral Coal	-1.237	0.101	-	0.999	239798.26
	(0.000)	(0.000)			(0.000)
Residential hydroelectricity	-0.387	-	-	0.998	2169.91
	(0.000)				(0.000)
Industrial hydroelectricity	-0.884	0.063	-	0.999	106828.16
	(0.000)	(0.002)			(0.000)
Wood	-0.207	-	-	0.966	454.18
	(0.000)				(0.000)

Table 2. Econometrical results of the SUR regression model by GLS for the dependent variable energy consumption by source of fuel[a].

[a] The null hypothesis probability is under parenthesis.

According to this econometrical result, the demand of most energy sources has positive relationship with income. Some of them (petroleum, natural gas, mineral coal, residential electricity) were not only positively related to income, but also have increasing elasticity (Tab. 2 and Fig. 3). The only two sources that seemed to be negatively related to growth are the residential hydroelectricity and wood (Tab. 2 and Fig. 3). In a 5% level of significance, just two of the sources consumption reacts to price change (natural gas and vegetal coal) (Tab. 2). But, even on those cases, the consumption is price-inelastic (Tab. 2).

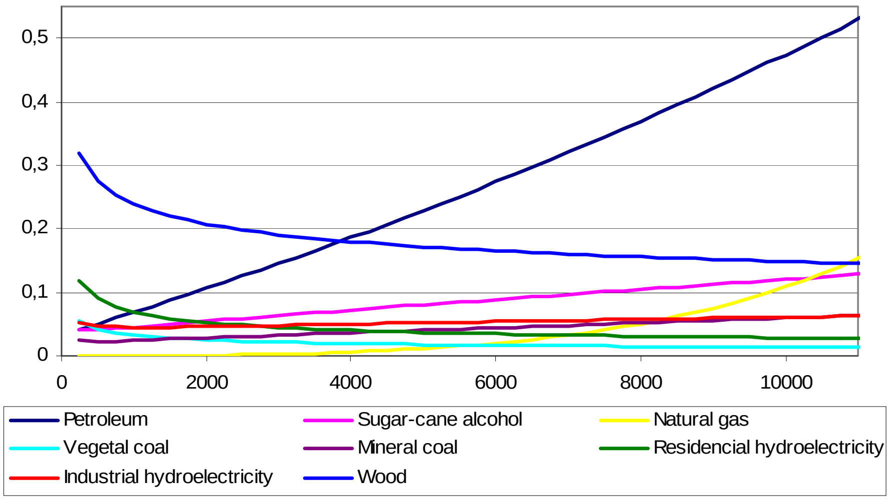

Figure 3. Brazil: adjusted energy consumption by source of fuel according to income (the price is fixed on 2002 level) (on 10^3 tEP/year).

Source: Based on the econonometrical results from the present study.

Based on these results, and fixing the energy prices on 2002 level for those eight sources of fuel, petroleum will be the main source of energy for Brazil (as a share of the total consumption) as the economy. Its share in the energy matrix will tend to stability just below 50% (Fig. 4). Other interesting result is the downward trend in the importance of wood as a source of fuel. From almost 50%, it drops steady but firmly to a value close to 10% on R$ 12,000 per capita income level (Fig. 4).

Natural gas, at 2002 income level (R$ 9,500.00), is just the fourth source of fuel. However, as income rises, its share tends to increase in the future to become one of the most important sources (the second most important, according to results) (Fig. 4).

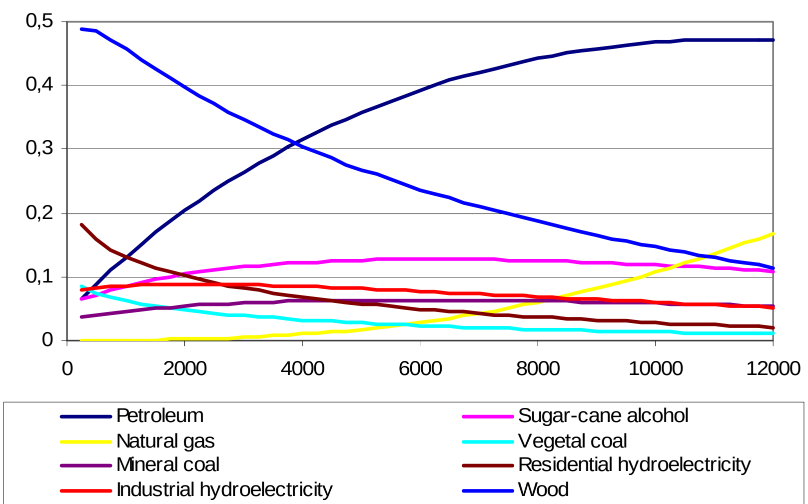

Figure 4. Brazil: adjusted energy consumption as a share of the total (%) on the total matrix by source of fuel according to income (the price is fixed on 2002 level).

Source: Results obtained in the study.

Other sources of energy tend to stability in values lower than 10%, in up-sloping tendency (sugar-cane and mineral coal) or down-sloping (industrial and residential hydroelectricity and charcoal) (Fig. 4).

The reduction on vegetal coal and wood would come by the fact that those sources of energy are with low calorific potential per volume and weight (once they produce a not complete combustion with a great degree of residuals). By the fact that energy sources must be transported and stocked, it is possible to say that those two sources, in terms of caloric potential, are costly comparing the other sources. And, once as a natural process of the economic growth comes the urbanization. It is possible to say that the stocking facilities get more expensive. So it is natural that the agents would prefer to use those sources of energy more efficient and with greater calorific potential.

The diminishing participation of hydroelectricity for residential use also would be explained as a natural process of growth. The answer for that, however, would come from the difference of the effects between total and per capita use: hydrological basin is a limiting for hydroelectricity expansion (it is not possible to create other basins), so the tendency is that on the limit most of the economically useful hydrological basin is got to be used to energy producing (or at least, the rate of growth have diminishing change); once that the reference used was the per capita terms, it is possible to say that the decrease on hydroelectricity for residential use it is not a function of its decrease on the total use, it probably means that its rate of growth is lower than the rate of population and economic growth.

Petroleum would be and it will continue to be for a long time the most important source of fuel. Most part of that is a consequence of: 1) its caloric efficiency, 2) constant research on extraction and transportation, 3) constant research for new or/and better uses, tradition on its use (it means that the industrial sector is habituated to use petroleum as a source of fuel), 4) it has very flexible uses (possibility to use on chemical industry) and easy to handle (ex: the vegetal coal must be dried or the nuclear energy that is unstable).

A negative effect of petroleum rising consumption is the negative environmental effects generated on combustion (emissions of elements such as sulphur, carbon, toluene, and other particular matter). Other natural impact, naturally, is a situation of great lack or great price impact (as it happened on petroleum crises).

4.2 Renewable X non-renewable

It also found that the share of renewable energy sources is decreasing as the economy grows. Not only that, but, in some level of income, the consumption of non-renewable sources of energy overcomes the renewable ones (Fig. 5).

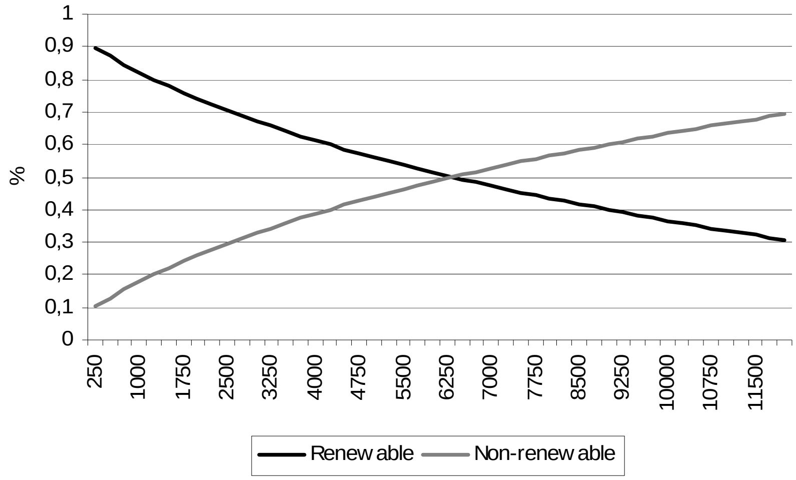

Figure 5. Brazil: adjusted renewable and non-renewable energy consumption as a share of the total (%) according to income (the price is fixed on 2002 level).

4.3 Carbon emissions

The carbon emissions are exponentially increasing on long-run[3] for both kinds of energy (renewable and non-renewable) (Fig. 6). Indicating that inverted U-shaped situation does not happen, or, that the marginal utility return of consumption provided is bigger than the marginal des-utility of emissions.

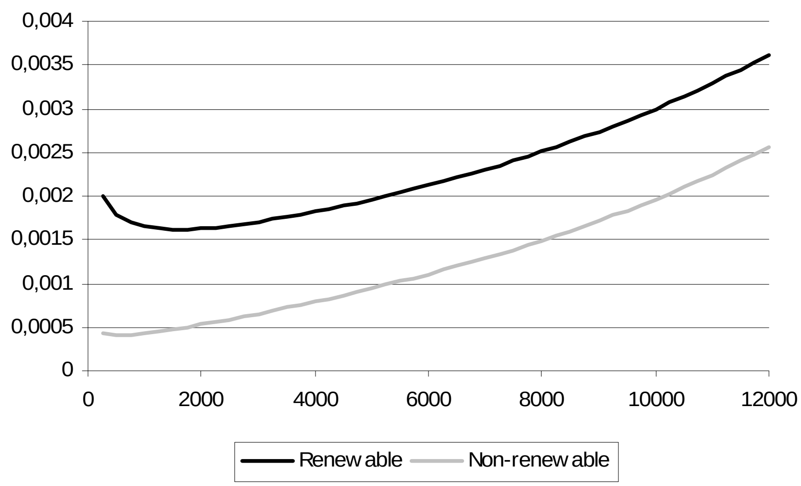

Figure 6. Brazil: per capita CO_2 (on Gg of CO_2 /year) emissions according to the level of per capita income (on 2002 R$).

5 CONCLUSIONS

The Brazilian economy must find some alternative sources. Apparently for petroleum, the solution for Brazil, at a very first moment, is the natural gas (Fig. 3). According to the econometrical results, along the economic growth, actually in higher

[3] On lower levels of income the emissions are decreasing (Fig. 6).

levels of income, the tendency is for a greater use of natural gas. However, those sources also tend to economic scarcity and generate externalities.

As exposed above, a bad result found is the tendency for intensification on the use of non-renewable sources of energy (Fig. 5) and the exponential increase on carbon emissions (Fig.6). Indicating that, the transition for a less pollution intensive and renewable energy matrix in Brazil would not naturally happen. It is required the change on the country's energy politics and polices (such as the use and research for alternative sources of energy, specially to substitute petroleum and natural gas).

The alcohol from sugar-cane and the hydro power also can be considered as successful alternatives sources of fuel that have already been implemented on Brazil. But as it had been observed on the study, its participation and level of use is tiny if it is compared with petroleum. And also, it is observed that their participation tend to reduce along economic growth.

What it has not been taking into count on the present study was some other important sources of fuel in Brazil. For example, nuclear power electricity would be a good alternative due to the great Brazilian reserve of uranium (almost as much as the petroleum reserves on energy equivalence) (MME, 2004). But, there are some negative aspects such as the great instability of nuclear reactions and the dangerous possibility of the non-peaceful usages of uranium.

Some other alternatives, not considered in the study, have already been tested on Brazil (such as the bio-fuels, solar-power and wind-power). But their price seemed to be a great barrier to its use. Considering that in the study have been used just the eight more significant sources of fuel, it is quite naive to believe that those sources of fuel (by present technology) would substitute petroleum (once most of energy source had a decreasing participation along economic growth).

But, backing again to what have been said, there is some degree of substitution between energy sources. That means that it is possible to substitute petroleum for others sources. That way, the research for new sources or for new technological equipments for the alternative fuels already used or not, would be a good solution to avoid the petroleum risk (environmental and scarcity).

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APPENDIX. Emissions CO_2 conversion factors per source of fuel (on Gg CO_2/1000 tEP).

Source of fuel	Conversion factor
Natural gás	2,34
Mineral coal	3,94
Wood	4,52
Sugar cane products	4,52
Petroleum	3,07
Vegetal coal	3,86

Source: MCT (2000).