THE ECONOMIC, ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS OF NEW POWER PLANTS: A SEQUENTIAL INTERINDUSTRY MODEL INTEGRATED WITH GIS DATA

Andre F. T. Avelino[1]

Geoffrey J. D. Hewings[1]

Joaquim J. M. Guilhoto[1]

RESUMO

O setor elétrico é responsável por considerável montante de emissões de gases de efeito estufa no mundo, porém é também o setor do qual a sociedade moderna mais depende para a manutenção da qualidade de vida e funcionamento do sistema econômico e atividades sociais. Invariavelmente, mesmo usinas de emissão zero de CO_2 apresentam algum impacto ambiental indireto devido aos efeitos econômicos decorrentes de seu ciclo de vida (construção, O&M e descomissionamento). Portanto, o aspecto de sustentabilidade sempre deve ser considerado no planejamento energético por meio da análise do equacionamento entre externalidades positivas/negativas em diferentes regiões do país. O presente estudo visa introduzir um modelo econômico sócio-ambiental baseado no *Sequential Interindustry Model* (SIM) regional integrado a dados de georreferenciamento a fim de identificar impactos econômicos, ambientais e de saúde pública a nível estadual para análises de planejamento energético. O modelo está baseado no *Impact Pathway Approach*, utilizando geoprocessamento para localizar variáveis sócio-ambientais para estimação de dispersão de poluentes e demanda de serviços de saúde. O objetivo final é desenvolver uma ferramenta auxiliar para a avaliação de diferentes cenários de expansão do setor elétrico brasileiro.

Palavras-chave: Planejamento Energético, Insumo-Produto, Economia da Energia, Georreferenciamento.

1 Faculdade de Economia, Administração e Contabilidade (FEA/USP), Regional Economics Application Laboratory (R.E.A.L), Faculdade de Economia, Administração e Contabilidade (FEA/USP)

ABSTRACT

The electrical sector is responsible for a considerable amount of greenhouse gases emissions worldwide, but also the one in which modern society depends the most for maintenance of quality of life as well as the functioning of economic and social activities. Invariably, even CO_2 emission-free power plants have some indirect environmental impacts due to the economic effects they produce during their life cycle (construction, O&M and decommissioning). Thus, sustainability issues should be always considered in energy planning, by evaluating the balance of positive/negative externalities on different areas of the country. This study aims to introduce a social-environmental economic model, based on a Regional Sequential Interindustry Model (SIM) integrated with geoprocessing data, in order to identify economic, pollution and public health impacts in state level for energy planning analysis. The model is based on the Impact Pathway Approach Methodology, using geoprocessing to locate social-environmental variables for dispersion and health evaluations. The final goal is to provide an auxiliary tool for policy makers to assess energy planning scenarios in Brazil.

Keywords: Energy Planning, Input-Output, Energy Economics, Geoprocessing Data

1. INTRODUCTION

Energy is an essential input in modern society and also it is one of the major sources of greenhouse gases (GHG) emissions, especially the electric sector, due to a world energy matrix concentrated in oil and coal resources. The Kyoto Protocol and IPCC (Intergovernmental Panel on Climate Change) reports on climate change issues identify sustainable development and rational resources use as key points to future. Thus, energy planning should consider not only economic impacts, but also environmental and social effects during the entire investment life cycle and idiosyncrasies of the chosen location.

Brazilian energy matrix is one of the least polluting in the world, especially due to its electricity generation, which has low pollutant emission indexes since it is concentrated in renewable energy sources (85.4%) such as hydropower, biomass and wind power plants (MME, 2009). Nevertheless, the generation portfolio is not too diversified with predominant supply of hydropower when considering all sources and when considering only "clean" energy sources (hydropower, biomass thermal and thermonuclear).

Since 2003 an electricity consumption rebound has raised per capita growth rates to 5% annually in Brazil (TOLMASQUIM, 2005). During all this phase, income elasticity measures for electricity consumption were superior to the unit, which has reflected in a consumption expansion higher than annual GDP growth and an increasing demand for generation infrastructure (TOLMASQUIM, 2005). In order to comply with this new scenario, several projects have been undertaken in the last years, particularly new gas-fired and thermonuclear plants (ANÁLISE, 2010).

Considering the fact that 22% of all greenhouse gas emissions come from energy use in the Brazilian case (MCT, 2009), which includes the electricity sector, it becomes essential to discuss externalities of the energy sources chosen in electricity generation expansion. Variables such as the amount of pollution, power plant location and local topography affects diversely public health and are important to be accounted during energy planning.

Several epidemiological studies have confirmed that even short term exposure to non-recommended levels of pollutants may lead to increases in mortality rates and the development of different morbidities (POPE, 2000). Nevertheless, pollutants concentration varies across regions due to the location of emission sources, microclimate dynamic, topography, weather and other factors, confirming the importance of a spatial analysis. Moreover, it is important to notice that pollutants emissions and climate changes have a reflexive effect both on the electricity system – affecting the own efficiency of certain power plants at low air quality levels – and in the local and national economy – due to demand shifts, lost working days and increase use of the health care sector.

In sum, recent scenario leads to new discussions about electricity generation portfolios that must be expanded and diversified under the premises of environmental sustainability. Due to these new parameters, different power plants must be assessed not only financially, but also socio-environmentally, considering regional idiosyncrasies, as this study intends. The proposed model allows assessing externalities in different regions and advantages/ disadvantages of different sites for a power plant's project. It is composed by a set of Regional Input-Output matrixes for the country and three other modules integrated computationally: Environmental Module, Energy Module and Health Module.

Next we describe the proposed model, discussing each module separately, and the dataset used. In section four some advantages and limitations of the model are presented and conclusions follow.

2. METHODOLOGY

2.1. Overview

Impact analysis is an essential feature for policy making, once it provides *ex ante* evaluations for the effects of new projects, and it is especially important in relation to large infra-structure investments. In the case of energy planning, *ex ante* evaluations are performed quite before the beginning of a project (construction of power plants, substations and transmission lines), involving the assessment of several options and distinct sites and their induced regional impacts. One must notice that besides cost differences, also economic multipliers, emissions and public health impacts differ spatially and a balance of positive and negative externalities shall be considered in energy expansion. Moreover, impact analysis allows addressing the benefits/problems different actors (decision-makers, enterprises, organizations and population) will perceive across regions.

The primary characteristic of large construction projects is their transient nature (ROMANOFF and LEVINE, 1980), i.e., economic impulses (demands) are heterogeneous through time. Their construction, in particular power plants, extends throughout several years before completion. Hence, these projects should not be addressed by static models, which compromise the accuracy of the analysis. The comparison of an equilibrium state before construction and the new equilibrium after the construction omits the existing dynamic in-between theses two time points. Construction is a complex sequential operation which demands different industrial and non-industrial inputs in subsequent phases. As each project has a unique cost, location and technology, distinct evaluations must be performed for each project individually and impact analysis is not transferable to other projects.

The proposed model is divided into four interconnected components – (1) Core Economic Model; (2) Environmental Module; (3) Energy Module; and (4) Health Module – with a feedback system in the end of the process to iterate the model. The model is computationally built and it allows assessing externalities in different regions and advantages/disadvantages of different sites for a power plant's project (Figure 1).

Using a regional Sequential Interindustry Model (SIM), direct, indirect and induced economic impacts of the construction phase of the power plant are estimated for each region. The advantage of using a SIM is being able to analyze how irregular demand flows in the different phases of construction dynamically impact the economy over several time periods. Then, once pollution coefficients are determined for each industry type, it is possible to estimate total pollution generated by the economy and the location of these emissions. Total pollution has, thus, two dimensions: physical units of the pollutant and source location. These variables are entered into the Environmental Module which estimates the dispersion of pollutants, resulting in the estimation of concentration-by-region data.

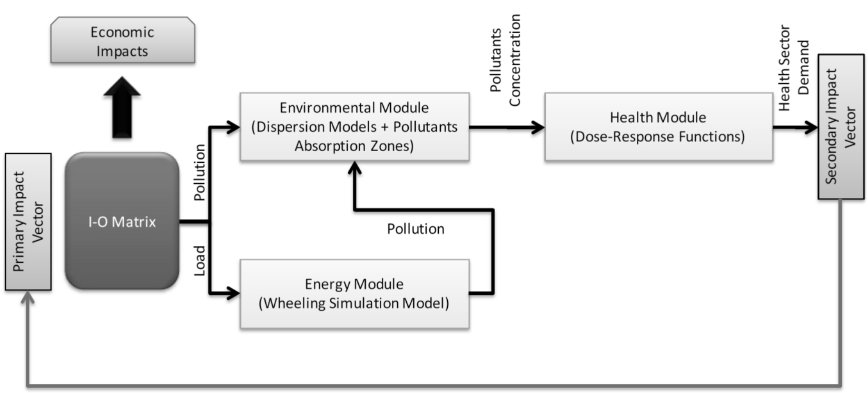

Figure 1 – General vision of the model

The required industrial output for the construction also raises the demand for electricity, which must be supplied with extra generation. The Energy Module emulates the ONS (grid operator) wheeling system and is applied to determine which power plants will be dispatched and consequent emissions by location. These outputs are inputs for the Environmental Module. Then, pollutants concentrations by location are applied in the Health Module that estimates the demand for health services/products in different regions. This demand is a new shock vector for the Input-Output matrixes that enters the process in an iterative fashion.

Geoprocessing information is used in several databases, providing information about population, pollutants concentration, topography, etc. for each location. A spatial vision of the entire process is achieved, allowing analysis of results in an aggregate way (economic, environmental and public health total impact) or disaggregated by region, thereby revealing more sensitive locations to pollution problems and/or economic benefits.

2.2. Economic model

Input-Output (I-O) models allow a detail vision of both macroeconomic and microeconomic impact of policy effects in a certain region, through the analysis of industrial interdependency within an economy. In the economy, the production of a good or service has two consumption destinations: either by directly consumed by final demand or used as input in the production of another good/service (intermediary consumption). Denoting by X_i sector i total production, *z* the intermediary consumption of its production by *n* sectors of the economy (including the consumption of the own industry) and Y_i final demand of sector *i*'s production, we have the following relation:

$$X_i = z_{i1} + z_{i2} + ... + z_{ii} + ... + z_{in} + Y_i \quad \text{Eq. 1}$$

It is important to state an intrinsic hypothesis to this I-O Model: interindustrial flows from *i* to *j*, for example, depends entirely on sector *j*'s total production in a certain time horizon. The technical coefficient (a_{ij}) is the relation between the share of sector *j*'s production used by sector *i* (z_{ij}) and sector *j*'s total production (X_j). It is supposed constant according to the premise of constant returns of scale (MILLER and BLAIR, 2009).

$$a_{ij} = \frac{z_{ij}}{X_j} \quad \text{Eq. 2}$$

Fixed technical coefficients imply a methodology limitation once the own economy dynamics causes coefficient variations over time and consequently, analysis and inferences of the models are valid only to a short term horizon (LABANDEIRA and LABEAGA, 2002). Replacing (2) in (1), rearranging in matrix form and solving the equations to determinate total output required to final demand (Y):

$$X = (I - A)^{-1} Y \qquad \text{Eq. 3}$$

$(I - A)^{-1}$ is Leontief Inverse matrix, which indicates all requirements for the economy's production, direct (from final demand) and indirect (from intermediary demand). It reflects how final demand propagates inside the entire economy (MILLER and BLAIR, 2009).

The Sequential Interindustrial Model (SIM) is built on the static I-O model with the insertion of a chronology in industrial processes. SIM is based on time-phased production, i.e., production process occurs sequentially in time, differently from the static I-O model which assumes that production occurs simultaneously during a single time-step. With this flexibility, one may represent different stages of manufacturing and transportation to final use, enabling to assess transient phenomena as the construction of power plants (ROMANOFF and LEVINE, 1981).

Two hypotheses must be made for the time interval *k*: (1) *k* equal for all industries and constant through time; and (2) all industries intervals are synchronized (ROMANOFF and LEVINE, 1981). Without these assumptions, there will not be feasible to formalize the model with difference equations and approach solutions which could be assess using traditional I-O framework.

Recalling the fundamental relation expressed in Eq. 1 and assuming that time is partitioned into discrete industry intervals, during the k^{th} interval the I-O model can be rewritten as:

$$X_k = Z_k + Y_k \qquad \text{Eq. 4}$$

Next step would be determining the coefficient matrix A for the economy. Nevertheless, as two production process with distinguish dynamics exist, responsive and anticipatory industries will differ in relation to time steps required. In the responsive model, the intermediate yield is expressed as:

$$Z_K = AX_{K-1} \qquad \text{Eq. 5}$$

Meaning that intermediate yield at interval *k* is linked to total supply at interval *k-1*. Contrary, in the anticipatory model, intermediate yield at interval k is supposed to be linked to total supply at interval *k+1*, resulting in:

$$Z_K = AX_{K+1} \qquad \text{Eq. 6}$$

The responsive model is derived by replacing Eq. 5 into Eq. 4 and the anticipatory model by replacing Eq. 6 into Eq. 4. Finally, using the double-sided Z transform one derives the pure responsive model and the pure anticipatory model, respectively:

$$X_k = \sum_{r=0}^{\infty} A^r Y_{k-r} \qquad \text{Eq. 7}$$

$$X_k = \sum_{r=0}^{\infty} A^r Y_{k+r} \qquad \text{Eq. 8}$$

Nevertheless, as the economic structure is composed of both anticipatory and responsive industries, one needs to define a mixed model which comprises the two production processes. This system may be formalized as:

$$X_k = A_1 X_{k+1} + A_2 X_{K-1} + Y_k \qquad \text{Eq. 9}$$

Hence, the solution takes the form:

$$X_k = \sum_{r=0}^{\infty} G_r (A_1, A_2) Y_{k-r} \qquad \text{Eq. 10}$$

Where $G_r(A_1,A_2)$ is a matrix function which has all path gains by the industries until time period *k*. This single region model may also be translated into an interregional model if one considers the matrixes in Eq. 9 as compositions of regional matrixes. Hence, for a two regions (L and M) example:

$$\begin{bmatrix} X_k^L \\ X_k^M \end{bmatrix} = \begin{bmatrix} A_1^{LL} & A_1^{LM} \\ A_1^{ML} & A_1^{MM} \end{bmatrix} \begin{bmatrix} X_{k+1}^L \\ X_{k+1}^M \end{bmatrix} + \begin{bmatrix} A_2^{LL} & A_2^{LM} \\ A_2^{ML} & A_2^{MM} \end{bmatrix} \begin{bmatrix} X_{k-1}^L \\ X_{k-1}^M \end{bmatrix} + \begin{bmatrix} Y_k^L \\ Y_k^M \end{bmatrix} \qquad \text{Eq. 11}$$

The only difference between pure systems and the mixed one is the production chronology. The production output of the former models is equal to the mixed production model, and also equal to that of the static I-O model.

In order to analyze impacts from construction of a power plant in relation to its pollution emissions, two extensions are required. Considering only two regions L and M, first, a pollution intensity (*p*) vector, which measures the amount of pollution emitted by industries in each region (tons of pollutant / R$ Million), is determined for each industry:

$$p_i^L = \frac{TP_i^L}{X_i^L}$$

Where TP^L is vector with total pollution in one year for each industry in region L. One must note that the electricity sector does not have a coefficient, once it will be estimated separately, using the Energy Module, avoiding double counting. Second, it is defined an auxiliary vector for energy intensity (*e*) that determines electrical consumption required (MWh) to produce R$ 1 million of a certain sector *i* at region L:

$$e_i^L = \frac{CTE_i^L}{X_i^L}$$

Where CTE^L is an nx1 vector with total electrical consumption in one year for each industry region L. This definition, however, differs from engineer definition of energy intensity. Intensity, in engineer, is measured by total energy requirement divided by added value in the product; in this paper, energy intensity is measured by total energy requirement divided by total production value, not just added value.

Aggregating the vectors p and e and considering the resumed form for the interregional model, analysis is done in two steps: first, we calculate total production ($\dot{X}$), direct and indirect, resulted from power plant construction ($\dot{Y}$). Those values are converted in emissions in order to determine total pollutants released during implantation ($\dot{P}_{construction}$). The $\dot{P}_{construction}$ vector contains pollution released by each industry in each region. It is the output of the economic model to the Environmental Module (pollution by location). Second, we estimate the electricity load for the construction ($\dot{E}_{construction}$) by postmultiplying the diagonalized total production ($\dot{X}$) by the energy intensity vector (e). This vector contains electricity requirements by the industries in each region and is the output of the economic model to the Energy Module (electricity by location). These vectors also have a time dimension from the SIM model.

2.3. Energy module

The Energy Module simulates the dynamic of the wheeling of the grid, which must maintain a static and a dynamic equilibria in order to keep the system's integrity. The basic operational idea for the grid administration is to minimize the energy price to consumers, subject to the transmission lines constrains. The concept is that inflexible power plants (hydropower, nuclear, wind and some thermal) are always connected to the grid and, thus, if there is an extra load in the system, they are preferred to increase generation to attend this demand.

In order to simulate the wheeling performed by ONS, NOWSS program was developed. The National Operator Wheeling System Simulation (NOWSS) is a simplified version of the network procedures and it is not intended to precisely estimate the energy flows and power plants but to show trends in the grid. The NOWSS is used to forecast a monthly dispatch due to extra loads in the grid and not to simulate daily operations. The program's inputs are monthly extra loads by state and the output total generation by plant.

Two important assumptions are made in this model due to its simplicity: (1) only interstate lines are considered (136 lines) and the transmission capacity is limited by the characteristics of the power line; (2) it is assumed that each state has only one substation and all power plants in this state are connected without distance costs to it. This substation is responsible for receiving and sending electricity and distributing it to consumers and has no capacity limitations (the power lines create this limits).

The program minimizes the cost between supply and demand, accounting for transmission distance and priority in the plants. Substation and lines form a graph with 27 vertices and 136 edges. The edges are oriented (energy flow can only follow one direct in the same line) and one or more edges can connect two vertices. The weight of each edge depends on the line capacity and an edge cannot be used anymore if its transmission limit is reached. The algorithm runs similar to Dijkstra's for finding the shortest paths between a source and every other vertex, however not only edges have different lengths, but nodes have different weights. After a new steady-state is reached, pollution from dispatched plants is estimated and sent to the Environmental Module (total emission, location and time period).

2.4. Environmental module

Both Economic and Energy modules send a dataset to the Environmental Module containing quantity of pollutants released to the atmosphere (and type) and the location of the source by time period (Figure 2). Using GIS data for meteorological conditions, a Gaussian Plume Model

(GPM) is applied for each region to determine the total concentration of pollutants at different distances from the source, considering the effect of one region in another.

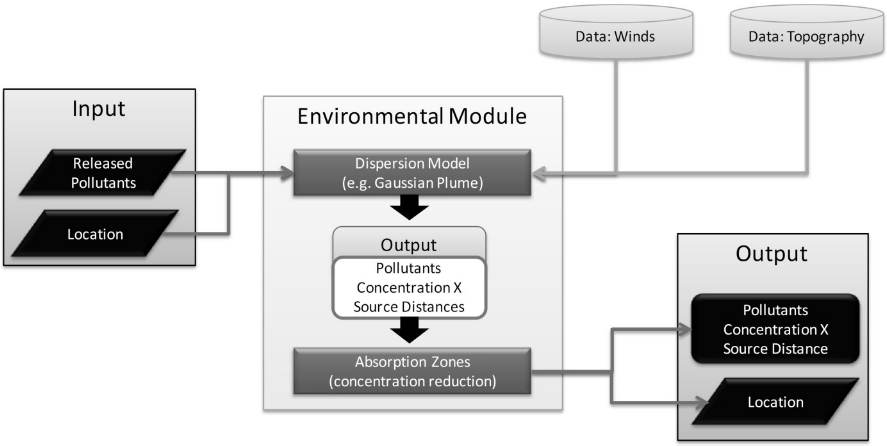

Figure 2 – Environmental Module

GPM assumes that continuous released pollutants are carried in a straight line by the wind and mix with the air both horizontally as vertically resulting in pollutant concentration with a normal (Gaussian) spatial distribution (EUROPEAN COMMISSION, 2005). The use of this model, however, is limited to a 100 km distance from the source (SALBY, 1996).

We use a simple model without extensions to account for chemical reactions, considering a homogeneous emission rate throughout the time period and concentration at ground level only. It is formalized as:

$$c(x,y,z) = \frac{Q}{2\pi u \sigma_z \sigma_y} \left\{ exp \left(\frac{-(z-h)^2}{2\sigma_z^2} \right) + exp \left(\frac{-(z-h)^2}{2\sigma_z^2} \right) \right\} \left\{ exp \, \frac{-y^2}{2\sigma_y^2} \right\}$$

Where **c(x,y,z)** is the atmospheric concentration at any point x meters downwind of the source, y laterally from the centerline of the plume and z meters above ground level; **Q**: emission rate; **u**: wind speed; **h**: stack height; $\boldsymbol{\sigma_y}$: cross wind standard deviation (measure of plume width); and $\boldsymbol{\sigma_z}$: vertical standard deviation.

After considering absorption areas (e.g. carbon sequestration zones), the final output of the model is concentration of pollutants by distance from source at several time steps. This data is entered in the health module for public health impact evaluation.

2.5. Health module

The Health Module receives data of pollution concentration, with location and time, for each pollutant considered from the Environmental Module (Figure 3). Adding it to preexisting pollution on site at time period *t*, total pollutants concentration (pc_t) can be estimated by region. Then, deleterious effects are forecasted through dose-response functions (DRF) which calculate the increased probability of pollution-related diseases and estimate the health sector demand caused by this non-recommended exposure. DRFs relate the concentration of pollutants an agent is been exposed to the physical impact on this receptor. We consider that the DRFs do not have any threshold point, as has been discussed by POPE (2000). The impacts of NO_x and SO_2 are assumed to increase indirectly from the particulate nature of nitrate and sulfate aerosols, and CO_2 impact is measured by CO effects (which derives from an inefficient combustion of CO_2).

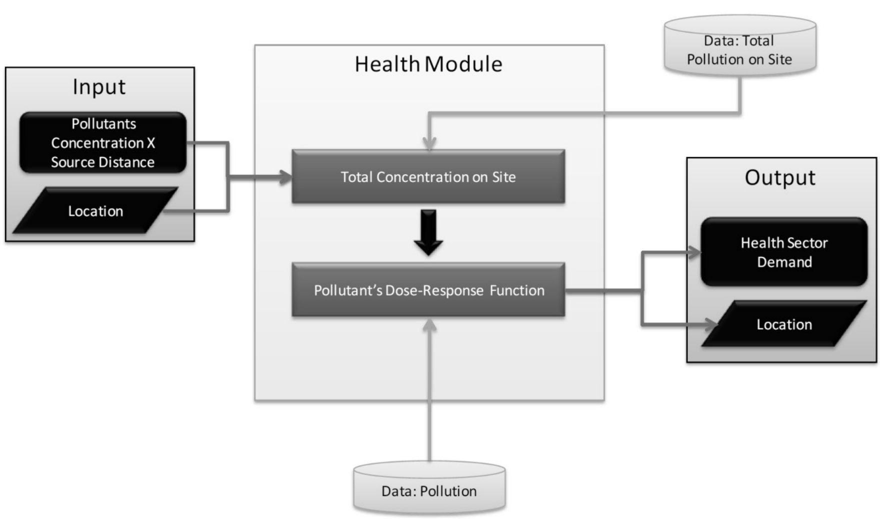

Figure 3 – Health Module

In order to transform public health effects into demand for health care services, the average cost per patient admitted in public hospitals is considered for each type of morbidity ($cost^{disease}$), besides the last hospital admission rate by region ($admis_{t-1}$). The final monetization of impacts is accomplished by estimating the number of excess diseases due to the pollution ($admis_{t-1}$*DRF(•)) and multiplying it by the cost for each morbidity. Hence, for region L, the health sector demand at time t (htL) depends on the current number of hospitalizations, the increase in morbidity cases and the local cost of treatment:

$$h_t^L = admis_{t-1}^L * DRF(pc_t^L) * cost^{L,disease}$$

It is important to notice that although the number of cases increases in a certain region, the effective health demand may not occur in this region due to a lack of available health care services. Hence, we consider that population can migrate to nearby regions seeking for treatment. Finally, a total health care demand is built and transformed into a new shock vector which iterates the model.

3. DATA

The national I-O matrix for Brazilian economy was derived according to the methodology presented by GUILHOTO and SESSO FILHO (2005a), while the estimation of the interregional I-O system was made following the methodology presented in GUILHOTO and SESSO FILHO (2005b). The 2004 matrix is divided into 12 sectors and 27 regions (26 states and Brasília). For the Energy Module, ONS (2010) and ANEEL (2010) provide information regarding type of fuel, nominal power, geographic coordinates and county where the power plants, substations and transmission lines are located (besides population density). GIS information regarding wind speed, bearing and latitude/longitude at county level is available in CEPEL (SWEARA, 2010) for 10km x 10km cells.

The most comprehensive available emission data for Brazil only covers CO_2, CH_4, N_2O, HFC-23, HFC-134, CF_4, C_2F_6 and CF_6 (MCT, 2009). But detailed disaggregation is given to the first three pollutants only. Therefore, carbon dioxide, methane and nitrous oxide will be assessed. Methane is not a toxic gas, hence its health effects will be neglected. Carbon dioxide will be evaluated through CO impacts and nitrous oxide will be measured as nitrogen oxide. The DRFs used in this work are based on GOUVEIA *et* *al* (2006) study for São Paulo. DATASUS (2010) has a large database with the number of hospital admissions by disease, total treatment cost, hospitalization period, mortality rate, etc., by federal, state and county levels for the Brazilian public health care system (SUS). This database will be used to assess health impacts. Available database allows county and state level accuracy in different stages of the model. The authors are still developing the program in Pascal and results and sensitivity analysis will be the focus of further works.

4. ADVANTAGES AND LIMITATIONS

As discussed above, I-O framework is not suitable for long-run forecasts once the economy' structure changes through time. Thus, considering using a computable general equilibrium (CGE) model is an alternative to better assess economic impacts. The simple GPM presented can be enhanced by adding extensions for airborne chemical reactions, and data regarding industrial location by county level shall increase the estimations accuracy. Nevertheless, although simple, the proposed model is able to proper address the transient demand from electrical investments and to provide economic, environmental and public health effects in spatial and temporal dimensions for comparisons between different scenarios.

5. CONCLUSIONS

As pollution is spatially dynamic, i.e. it is emitted at the source but its impacts extend to the length of dispersion it produces, to proper evaluate its externalities, models coupled with spatial components shall be used. In this study, a hybrid top-down/bottom-up model is proposed, coupling a regional economic model with GIS data and with electric-social-environmental specifications. For each power plant project it estimates the total economic impact, effects on the wheeling dynamic of the electric grid and public health impacts due to pollutants dispersion. Through this model, several sites for the construction of a new plant can be compared regarding positive/negative externalities in the micro-region (state level) and macro-region (country level).

Due to the large Brazilian territorial extension and its generation portfolio, this type of analysis is particularly important once, as the grid is integrated, electricity generation and consumption may not occur in the same region, meaning that the potential pollution burden may not be balanced with local economic development. The model provides a spatial vision of the entire process, allowing results to be analyzed in an aggregate way (economic, environmental and public health total impact) or disaggregate by region, determining more sensitive locations to pollution problems and/or economic benefits.

In sum, planners can benefit from this model exploring the impacts of diverse energy sources and locations, assessing economic, environmental and social aspects of each alternative. Electricity will still remain as an essential input in the future as well as its environmental concerns. Sustainability is a challenge to be addressed today for a long-term benefit. The more tools society can rely on, better decisions can be made and a cleaner future planned.

REFERENCES

Análise. Análise Energia: Anuário 2010. São Paulo: Ibep, 2010.

ANEEL. BIG – Banco de Informação de Geração. 2010. Available in: <http://www.aneel. gov.br/15.htm>. Access in May 28, 2010.

DATASUS. Banco de dados do Sistema Único de Saúde. 2010. Available in <www.datasus.gov.br>. Access in May 28, 2010.

European Commission. ExternE – Externalities of Energy: Methodology 2005 Update. Luxemburg: European Communities, 2005.

Gouveia, Nelson *et al*. "Hospitalizações por causas respiratórias e cardiovasculares associadas à contaminação atmosférica no Município de São Paulo, Brasil" in Cadernos de Saúde Pública, v.22, n.12, pp.2669-2677, 2006.

Guilhoto, Joaquim J. M. *et* Umberto A. Sesso Filho. "Estimação da Matriz Insumo-Produto a partir de Dados Preliminares das Contas Nacionais" in Economia Aplicada, Ribeirão Preto, v.9, n.1, april-june 2005a.

Guilhoto, Joaquim J. M. *et* Umberto A. Sesso Filho. Estrutura Produtiva da Amazônia - Uma Análise de Insumo-Produto. Belém: Banco da Amazônia, 2005b. 320 p.

Labandeira, Xavier *et* José M. Labeaga. "Estimation and Control of Spanish Energy-related CO_2 Emissions: an Input–Output Approach" in Energy Policy, v.30, pp.597-611, 2002.

MCT. Inventário Brasileiro das Emissões e Remoções Antrópicas de Gases de Efeito Estufa: Relatório Preliminar. Second Edition. Brasília: MCT, 2009.

Miller, Ron *et* Peter Blair. Input-Output Analysis: Foundations and Extensions. New Jersey: Prentice Hall, 2009. 464p.

MME. Balanço Energético Nacional 2009 – Ano Base 2008. Rio de Janeiro: EPE, 2009.

ONS. Histórico da Geração Elétrica. 2010. Available in: <http://www.ons.org.br>. Access in: Apr. 16, 2010.

Pope, C. Arden. "Invited Commentary: Particulate Matter-Mortality Exposure-Response Relations and Threshold" in American Journal of Epidemiology, v.152, n.5, pp.407-412, 2000.

Romanoff, Eliahu *et* Stephen H. Levine. "Impact Dynamics of Large Construction Projects: Simulations by the Sequential Interindustry Model" in Discussion Paper No. 80-2, Regional Science Research Center, 1980.

Romanoff, Eliahu *et* Stephen H. Levine. "Antecipatory and Responsive Sequential Interindustry Models" in IEEE Transactions on Systems, Man and Cybernetics, v.11, n.3, 1981.

Salby, Murray S. Fundamentals of Atmospheric Physics. San Diego: Academic Press, 1996.

SWERA. CEPEL - Brazil Wind Data (10km). 2004. Available in: <http://swera.unep.net/>. Access in: Apr. 16, 2010.

Tolmasquim, Maurício T. (Org.). Geração de Energia Elétrica no Brasil. Rio de Janeiro: Interciência, 2005. 198p.