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Top-down versus bottom-up: Coupling both modelling approaches for a prospective study on biofuels

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Abstract: Since in the first and decisive stages of their development, bio-energy potentials are highly dependent on favourable public intervention and its ability to overcome the lock-in effects that maintain the hegemony of conventional fossil energies, bio-energy potentials should not only be queried in terms of costs and available volumes. Public support for a given bio-energy is all the more legitimate when its future potential can be proved high. For that matter, prospective studies, which include both the techno-economic aspects of a given bio-energy and the economic conditions of its emergence and development, are required. The engineers' and the economists' points of view regarding technical change, must be combined into some hybrid bottom-up top-down models, allowing for the consistency of technological choices at the micro-level with some macro-economic aggregates, namely activity indicators.

Central points to be considered are the possible feedback impacts of technological choices on the macro-economy via changes in the technical coefficient. The role of prices needs special attention in this matter. The hybrid model presented here has been used for a prospective study on bio-energies in Brazil and another on biofuels in France. It essentially consists of the iteratively linked projections of both the Input-Output table and the energy balance of the economy. We shall describe the modelling methodology, the main hypotheses and "experts sayings" the model relies on, and finally illustrate with some results on biofuels in Brazil.

Keywords: Energy-economy modelling, biofuels, environment, Brazil.

Introduction: The economic context of bio-energy emergence

In most countries, actual bio-energy productions remain not only far below their potential but also far below the developments that have been considered in energy outlooks some years or even decades ago. One main hindrance to the emergence of a large scale production of bio-energies lies in their lack of competitiveness compared to alternative energies, namely fossil energies, and lack of profitability compared to alternative activities for actors involved in the various sectors (agriculture, energy, etc). Both competitiveness at the consumption stage and profitability at the production stage are dependant on the actual incentive system, which includes all prices, tax and subsidies, as well as norms or quotas if any.

For bio-energies to emerge, the issue at stake is not purely their costs, but the whole incentive system. As the price of a good is made up of the prices of all goods and of the production factors used for its production, ant study of an incentive system requires a look at the economy as a whole, namely its different sectors, its labour market where the wages -that is labour costs- are set, the capital market where interest rates -that is capital costs- are set, etc. Obviously, a study of bio-energy cannot be carried out without consideration of macro-economic parameters, the associated incentive system, as well as possible exogenous changes.

In a context where ecosystems and economies are endangered by the depletion of natural resources and by pollution, a major source of exogenous changes is environmental policy. How and to what extent can concerns for the environment lead to measures that effectively promote bio-energies? For which of the energy chains –i.e. a chain of technological choices from the biomass type to the final service- can initial support for the sake of environment or other public policy objectives trigger viable development?

The most direct way of answering these questions combining both policy analysis and technological change outlooks is to look at how public spending corresponding to a better taking into account of environmental variables can affect potentials and costs in the different bio-energy chains trough R&D investment and subsidies or specific fiscal measures. Given the time scales involved in environmental matters as well as in energy matters, namely with respect to infrastructure, this bottom-up approach needs to be conducted for sufficiently long time periods to allow for diffusion processes to take place through learning and scale effects, and for lock-in effects in favour of fossil energies to be overcome. Conclusions drawn regarding the impact of public policy on bio-energies that are restricted to their current feasibility and immediate performance would not suffice to inform the public decision-maker on the viability of some energy chains he may wish to choose and promote. Long-term potentials and costs of bio-energies must be an integral part of decision factors, all the more when irreversibilities of technical choices are involved.

When tackling the long-term with learning curves and diffusion asymptotes, a bottom-up approach has a major limitation, that of considering the evolution of some techno-economic variables only, "everything else being equal". It is not realistic, in the long-run, as obviously the economic context will evolve, namely relative prices will change because of structural changes in the economy.

In order to take into account the evolution of the whole context, a top-down approach is required in which macro-economic aggregates can be projected consistently in a common framework. For this framework to include details about technologies, namely, the hypotheses concerning the potentials and the costs of bio-energies, linkages are necessary between both bottom-up and top-down approaches.

The purpose of the paper is to detail the principles and the methodology for coupling bottom-up and top-down approaches. It focuses on their application to the case of biofuels in Brazil, an energy chain whose feasibility has remained completely dependant on public support, therefore extremely vulnerable to changes in policy.

I. Bottom-up versus top-down modelling approaches

The debate among energy experts in the 80's that fuelled the "bottom-up versus top-down controversy" first illustrated how important it is to choose the right modelling approach for prospective studies on biofuels and for their evaluation in policy terms; second, emphasised strong and weak points of each approach; and third, made a case for combining both approaches.

The debate appeared after the termination of an era. Before the first oil shock, energy matters were considered to be relatively easy to be represented with models focusing on the supply side, energy demand being seen as an exogenous variable, and quite steadily related to energy growth. Its income-elasticity remaining quite constant, energy demand was of no complexity and only energy supply remained to be optimised.

After the first oil shock, a series of changes occurred, that caused important variations in the income-elasticity of energy consumption. Among these changes were:

- the dematerialization of the economy, for which the tertiary sector, i.e. of services, got the leading role in industrialised countries, while high energy consuming industries moved to developing countries;
- substitutions between energy sources after the rise of oil prices greatly modified energy relative prices and dangerously increased the energy bills of oil importing countries, inducing them to adopt a strategy of substituting imported oil with locally produced energy (in Brazil and France, for instance);
- technology innovations, stimulated by limitations to energy productions and the subsequent price rises, accelerating technical progress.

The end of a regular correlation between energy consumption and economic growth required if not the development of new models, at least the improvement of existing ones. Propositions for a better taking into account of the above-mentioned changes, appeared through the top-down versus bottom-up debate, from which our scheme of an hybrid model derives. Our actual aim is to integrate both the costs and profitability of technologies, as well as macro-economic costs in terms of balance of payments, social costs of unemployment and environmental costs of GreenHouse Gas (GHG) emissions.

After a description of both top-down and bottom-up approaches and their respective evolutions in response to their initial weaknesses, the conclusion drawn (Grubb et al., 1993) is that the core methodological difference lies in the representation of technological progress. It is dis-aggregated, from the engineer's standpoint in bottom-up models, and more aggregated, from the economist's standpoint in top-down models.

I-1. The top-down approach

Top-down models are borrowing to both neo-Keynesian and neo-classical theories, with macro-econometric models on the one hand and CGEM on the other hand :

In neo-Keynesian models, parameters are estimated econometrically within equations that generally simulate potential global production as a function of factor inputs such as capital (K) and labour (L). When energy (E) and materials (M) are included as production factors, production functions are called KLEM functions. When even more details are added, models rely on input-output tables so as to describe relations amond sectors.

In the field of economic analysis, neo-Keynesian models have the advantage of being able to take into account structural unemployment, stemming from insufficient labour demand in the long run.

At their beginning, in the 50's and 60's, when Keynesian economics was in its golden age, economic policy analysis comprised the building of top-down models and applied econometrics to historical data on consumption, prices and revenues so as to estimate elasticities of demand. As energy demand growth closely followed economic growth, estimates from macro-econometric models were satisfactorily close to real values.

This was no longer the case at the end of the 60's when, even before the first oil shock, inflation continued to rise without any decrease in the unemployment rate. Keynesian postulates became less valid. Later in the early 70's, the unemployment rate actually increased with inflation. On the supply side, productivity gains that had been transferred to wage earners up to that time were reduced to zero, preventing the Keynesian "multiplier" to operate through increases in demand. In this context, neo-classical theory regained authority and became hegemonic, while Keynesian theory lost ground, undergoing criticism for neglecting basic economic assumptions on consumer preferences and technological choices and relying excessively on ah hoc hypotheses, such as prices and wages rigidities, and finally being unable to detect structural changes. From that time on, the macro-economic paradigm anchored itself on the rationality theory.

Computable General Equilibrium Models (CGEMs), then became the methodological standard, referring to Walrasian intertemporel equilibrium models, that stressed the supply effects. In CGEM or optimal growth models, which are based on resource allocation, on utility maximisation and cost minimisation and on market equilibrium for all goods, the price of each is equal to its marginal production cost. In a CGEM, the results are determined by capital accumulation dynamics, as well as by the values taken by the exogenous growth of production factors availability or of their productivity.

This type of model presents the main advantage of identifying feedback effects between the energy system and other sectors of the economy, thereby measuring macro-economic performance nationally compared to internationally, of energy markets or the whole economy.

However, by relying on "state" functions rather than "path" functions, CGEM do not inform about the trajectory towards equilibrium after an exogenous shock, and possibly therefore under-estimate transition costs from one equilibrium to another. Also, because of their assumptions of a perfect equilibrium in all markets, CGEM tend to omit existing structural unemployment. Moreover, their need for differentiable function and convex production functions requires assumptions of non-increasing returns-to-scale and excludes fixed costs that would introduce discontinuity and non-differentiability.

Economic models that focus on supply effects use the dual form of the production function within a cost minimisation problem, the production function entering the constraint[1]:

$$\min C = \sum_{i=1}^{n} p_i x_i$$

subject to:

$Y = f(x_i)$

where :

C : total cost

p_i : price of factor i

x_i : production factor i

Y : production function

I-2. The bottom-up approach

In techno-economic models where the demand side is privileged, total energy consumption in a country can be computed as the sum of energy demands of all sectors of her economy. For each sector or branch "s", consumption can be computed as follows[2]:

$E_s = \sum E_i.N_i$

where:

E_s : final energy total consumption in s;

E_i : final energy consumption by facility i in sector s;

N_i : available facilities of type i.

This simple model can be detailed when the following information is available:

θ_i : use-to-capacity rate of facility i ($0 \leq \theta_i \leq 1$)

r_i : energy efficiency of facility i ($0 < r_i < 1$)

U_i : useful energy consumption necessary to the use of facility i at its full capacity

n : number of firms belonging to sector s

t_i : equipment rate, i.e. the number of facilities of a given type, divided by the number of production units.

Since

$E_i = (\theta_i / r_i) \cdot U_i$,

then

$E_s = n \sum t_i \cdot (\theta_i / r_i) \cdot U_i$

Hence, if data on the shares of energy consumption by facility (λ_i) are known in sector s, the energy consumption can be written in even greater detail:

$E_s = n \cdot (t_i / \lambda_i) \cdot (\theta_i / r_i) \cdot U_i$

[1] The solution to the minimisation problem comes from the Lagrangian :

$$L = \sum_{i=1}^{n} p_i x_i - \lambda(Y - f(x_i))\_and\_\frac{\partial L}{\partial x_i} = 0$$

[2] For further details, see PERCEBOIS (1989, p. 147).

Within a dis-aggregated model, technical progress and structural changes represented by the evolution of such parameters as in the equation above, can be easily identified.

Starting from this simple basis, techno-economic models are developed, alternatively along four different lines described by Lapillone (1993).

> **Accounting models** constituted the first generation of bottom-up models. The facts that their variables are mainly exogenous, prices are not explicit and the dynamics are not included, which would explain the evolution of socio-economic variables, of technological choices or substitution between energy sources, are only some of their shortcomings.
>
> The second category of **techno-econometric models** allows for the representation of energy savings and energy substitutions within econometric relations, and hence for the identification of structural and behavioural changes. Nevertheless, exceptional events, such as a cold wave, can bias techno-econometric model results.
>
> The third category includes **simulation models**, a generation on from accounting models, in which energy prices, investment behaviours and technology costs are simulated so as to compute potentials for energy savings and energy substitutions. Compared to techno-econometric models, this type of model presents the valuable advantage of relying non exclusively on observed data but also on assumptions and forecasts regarding technological adoption. Moreover, they are sufficiently flexible to include market imperfections.
>
> **Optimisation models** belong to the fourth category and differ form simulation models mainly through their representation of consumer choices. Optimisation models assume well-informed consumers who behave rationally under given constraints and thus choose the best options, making it difficult for the representation of the aforementioned market imperfections.

According to Destais (1993), optimisation models have the best features to tackle questions on energy fluxes in the energy system, investment needs, possible energy savings, and the minimal discounted cost of producing energy under technical, economic and environmental constraints.

Bottom-up models, originally built for one given sector, provide a dis-aggregated picture of demand and/or supply and also indicate potential productivity gains, thanks to some explicitly described technologies, or the potential for substitution by carbon-free technologies. So, in order to eventually reveal structural changes in the economy occurring when economic growth and energy consumption no longer evolve together as they used to, detailed information on technologies, such as the diffusion rate of facilities and their use-to-capacity ratio, heat loss rates in building, transported goods in terms of ton.kilometer, etc., is required. No doubt, these bottom-up models introduced great changes in the field of energy prospective, making energy demand no longer exogenous.

From a methodological point of view, the bottom-up approach has the following shortcomings:

- an excessive number of exogenous variables, which might cause large deviations from reality when information is not reliable and approximations multiply margins of error;
- the impossibility of measuring feedback effects, whenever bottom-up models take into account energy prices, the price system being computed with partial equilibrium "*ceteris paribus*" assumptions that energy price does not influence the prices of other goods and services;
- the impossibility of assessing the macro-economic consistency of results, for instance, whether required investments in the energy sector can be financed by national savings, whether it will have eviction effects on the investments of other sectors causing productivity slow-downs therein;
- the difficulty in measuring macro-economic costs. Unlike micro-economic costs that can be easily computed thanks to cost-benefit analysis, macro-economic costs, in terms of GDP losses, are not easy to measure. Yet, some decisions taken at the micro-economic level can

- affect macro-economic indicators, for instance, when an efficient technology is strongly dependent on foreign resources, and the necessity to export is implied, with the possible result that economic growth is affected.

To confront these problems, bottom-up approaches have been refined so as to introduce more and more information in the economic context.

Simultaneously, top-down approaches have been refined so as to better explain technical data. Differences in the structures of models have become less important than *ad hoc* hypotheses.

I-3. Conclusions drawn regarding the bottom-up versus top-down controversy

Debates on methodological choices for modelling that point out the strengths and weaknesses of each approach have shown that top-down models better tackle the implementation of economic or environmental policies, whereas bottom-up models better evaluate the potential for energy efficiency improvements and a reduction in GHG emissions.

Basically, and this already calls for the integration in a same model of both top-down and bottom-up methodologies, each methodology tends to neglect what it takes as externalities. According to Grubb et al. (1993):

- top-down modelling studies, which reflect the economist's point of view and treat technical change in an aggregated way, tend to underestimate the potential for low-cost efficiency improvements (and overestimate abatement costs) because they ignore a whole category of gains that could be tapped by non-price policy changes, whereas;
- bottom-up end-use modelling studies, which reflect the engineers' point of view and treat technical change in a dis-aggregated way, overestimate the potential (and underestimate abatement costs) because they neglect various "hidden" costs and constraints that limit the uptake of apparently cost-effective technologies.

The aforementioned conclusions drawn already explain why the results of the impact of environmental policy, in terms of energy technology development, can quite widely differ between top-down models and bottom-up models. Additionally, a series of market imperfections makes optimality inadequate to represent the real world. For instance, neither an optimal taxation system nor the best technologies can be implemented due to some factors that intervene as externalities, for example:

- risk aversion: a producer might prefer to continue producing what the market has already widely accepted than produce completely new products. Likewise, a consumer might be informed about the higher efficiency of a new product but still prefer the traditional, less efficient product, for lack of proof on the efficient product;
- imperfection of incentive systems: new price regulations, tax and tariffs can reduce national competitiveness internationally instead of improving the efficiency of the economy
- information costs: the reduction in information asymmetries between technical alternatives, either on the supply or the demand side;
- transaction costs: the costs of reducing market imperfections, such as:
  - market barriers, monopolies, subsidies, etc.
  - hidden costs: to develop trust in the performance of an efficient product, a time and effort cost is incurred associated with learning time and effort and to the technology diffusion, and
  - the private costs, such as the installation costs of efficient equipment, which are not always taken into account in the analysis. These costs are generally difficult to estimate.

Based on the basic principle of leaving an inefficient context for a sub-optimal context that is as close as possible to the optimal context, the model must include all the externalities that can possibly be analysed.

As such, there is a consensus on hybrid models that tempers engineers' optimism regarding technology diffusion by the taking into account of market imperfections and entry barriers, that also tempers economists' pessimism by taking into account innovations in aggregated models. For such models to successfully combine both approaches, neither the macro-economic nor the techno-economic part should be greatly dis-aggregated.

II. Linking bottom-up and top-down approaches

The linking of top-down with bottom-up approaches allows for consistency in various of some macro-economic aggregates and technological choices at the micro level. Structural changes made through changes in consumption modes or through technological changes can be explicitly integrated into the same model, allowing both for the analysis of economic policies and the computation of reduction potentials for energy consumption or GHG emissions.

In many hybrid models, the only linking done consists of the use of activity indicators, such as added value, which is exported from a macro-economic module to be imported into the techno-economic module. Our model was developed after we had made the following observations:

First, using the macro-economic module upwards from the techno-economic module in such a way, prevents feedback impacts to be taken into account.

Second, it must be kept in mind that the same added value can account for different material bases, therefore value added should be detailed in terms of volume, not only price.

Third, because the emergence of bio-energy implies new modes of development, both upwards regarding biomass availability with such issues as land-use and downwards regarding energy demand depending on the structure of the productive economy, agricultural activity must be explicitly represented.

Fourth, there are eviction effects of energy choices in terms of investments in other sectors that should not be ignored.

Fifth, the role of prices must be explicit. As such, the analytical framework can either be of partial or of general equilibrium. In a general equilibrium, all goods and markets are integrated into the same equation system where price- and revenue-effects are taken into account. The issue is then the role of prices in this system: are they the sole determinant of quantities ?

Sixth and lastly, expert sayings can be used as a way of taking into account market imperfections. What the experts say with regards to politics, economics, and techniques amend observed past trends.

II-1. The model

The model used for biofuels in Brazil simultaneously projects the Input-Output (I-O) matrix and the whole energy balance[3]. These two modules are structured in a manner that aims to display the priorities, expertise and experiences of the country, according to the availability of national data. The projection module for the I-O matrix consists of eight sectors, four of which belong to the energy sector. The energy balance is built up from five energy sources and ten energy consumption sectors.

The I-O matrix is projected in value and physical units according to assumptions made by the Government about GDP growth, public spending and trade balances. In the case of Brazil, household consumption is calculated as the difference between income and investments and net export requirements, which is a necessary constraint to growth and the payment of the foreign debt, respectively.

However in our model, household consumption and investment are grouped into three social classes. Class 1 earns up to 2 minimum wages, Class 2 from 2 to 10, and Class 3 earns more than 10 minimum wages.[4]

[3] For further details, see COSTA (1999).

[4] In 1995, our model base year, 1 minimum salary was equal to 70 R$ per month or almost 70 US$ per month.

One constraint to minimum consumption by product is imposed on a Cobb-Douglas demand function. Consequently, consistency in the government's views on macroeconomic policies and the energy options analysed may be checked.[5]

Relative prices are calculated according to assumptions made about the development of real wages and gains in productivity for production factors, particularly labour and energy. Detailed descriptions of these production factors allowed us to check if an energy option alters the capital-labour ratio in a manner that is consistent with the scarcity of these production factors.

Variations in prices and quantities by sector that are calculated in the I-O matrix projection are transferred to the energy balance projection module. It should be stressed that residential sector consumption in the energy balance is associated with household energy consumption in the I-O matrix. Should the government pursue austere policies that restrict household consumption, energy consumption in the residential sector would be affected.

Energy consumption in the transportation sector is not associated with GDP as usually done in bottom-up models, but with intermediate consumption and final demand. Energy consumption in other sectors rises in parallel to its outputs and energy intensity trends.

Technical progress in each sector is taken into account in the energy intensity and energy efficiency curves. These curves are built up as a function of time, energy prices and experts' judgements (e.g. fixing asymptotes on trends)[6]. Prices and time also affect the substitution process among the sources of energy consumed by the various sectors.

Technical progress and the process of substitution among energy sources trigger structural changes that must be considered in macroeconomic projections if we accept that the energy sector plays more than a marginal role in the economy.[7] New technical production coefficients are introduced into the I-O matrix projection until equilibrium is reached.[8]

The model and its two parts, macro and techno, is illustrated in the graph below and its 3 blocs.

In the first bloc: the required six main *ad hoc* hypotheses are given:

- price of imported fossil fuels (PF)
- labour productivity increase (ro)
- real wages evolution (omega)
- profit rate (phi)
- technical coefficients (delta)
- imports rate (chi).

In the second bloc, for the projection of the I-O table, economic growth is driven by household consumption -or by investments, depending on the availability of data. Exports are used as an adjustment variable according to assumptions made about export rates.

In the third bloc, the energy balance is projected.

Ad hoc hypotheses play on the relative production prices. These prices are transferred to the module where final demands (consumption and investment) are computed for each good. Total final demand is determined by the real income according to the hypothesis on real wage evolution. One main function of the macro-economic part of the model is to ensure consistency between prices and volumes in the whole economy. On the one hand, prices affect the composition of the consumption basket, on the other hand, for the hypothesis on the real wage increase

[5] Note that the model is not restricted to the supplier side, as constraints on the demand side are also taken into consideration.

[6] Note that our results are based not only on past information but also on future forecasts.

[7] This is a hypothesis intrinsic to bottom-up models, and assumes that substitution among energy sources would have no relevant impact on the rest of the economy.

[8] The use of linear production functions following a Leontief format after correcting the technical production coefficients ensures equilibrium between supply and demand.

to be consistent with the new price system, the shares of consumed goods are re-introduced to calculate prices. This is why the link between price projection and final demand projection is represented by a double arrow.

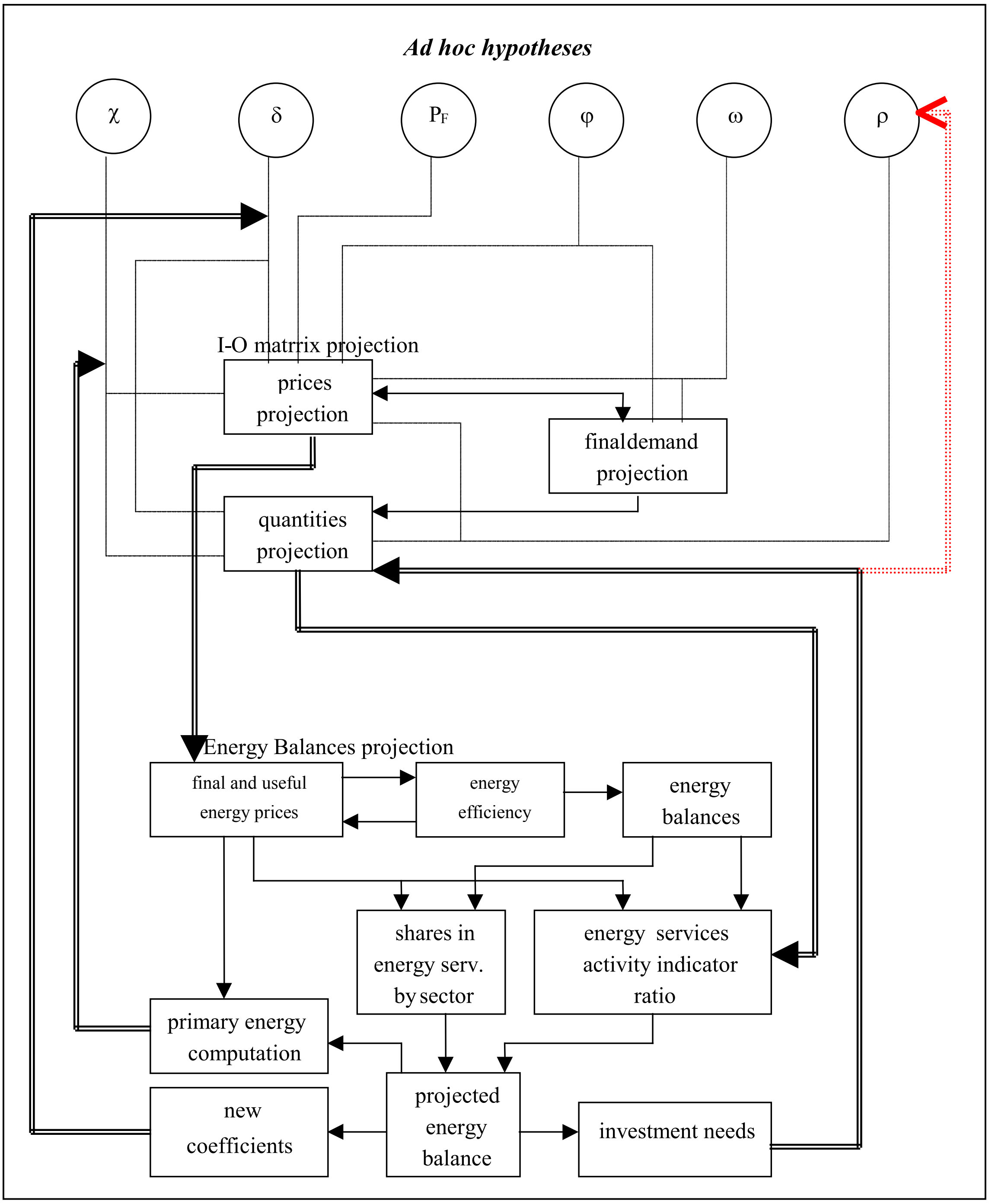

Figure 1. Simultaneous projection of I-O matrix and energy balances (Costa,1999)

In the third box of the second bloc, again for the macro-economic projection, technical coefficients of intermediate consumption (delta) and of investment (k), imports (M), exports (X) and final demands of households (DFM) and of the government (G) are used to determine the produced quantities.

In the third bloc, for the projection of energy balance, prices and quantities computed in the macro-economic projection are introduced. Energy intensities of different sectors are computed through the ratio between energy services and activity level as a function of prices and of time as in the past and according to what the experts say for each source of energy. This is where assumptions about consumption modes (changes in behaviour, for instance) intervene.

Prices also affect energy efficiency. Efficiencies are used in the energy balance and to compute the price of energy services. Substitutions occur within certain limits imposed by experts.

A new energy balance is projected. New technical coefficients for the energy sector are transferred to the macro-economic bloc.

II-2. The role of prices and experts sayings

It is crucial to clearly state reactions to prices, otherwise the impact of public policy measures affecting prices on the effective promotion of bio-energies cannot be properly estimated. Therefore, a number of difficulties must be tackled because energy experts do not know how energy prices affect non-energy goods and production factors. For instance, sectors that intensively consume energy or energy-intensive goods are not always flexible in terms of energy substitution, though price elasticities that are very small in the short run might be much larger in the longer run.

In our model, instead of being supposed constant and estimated on past data, the values taken by elasticities are computed according to past trends and experts sayings. This source of quantified information is used on asymptotes, trend inflections, and on values taken by some parameters at a given time, thus inducing the speed of structural changes and behaviour

Procedures are such that the model does not rely on various axiomatic hypotheses of the perfect competition framework (convexities, perfect information, non-increasing scale effects…). We still use continuous functions, thereby avoiding the identification of fixed costs, and aggregated production functions, thereby supposing techniques are generic.

III. Some results on biofuels

Two scenarios were elaborated for Brazil for the year 2010. At the macro-economic level, the business-as-usual (BAU) scenario takes into account the government's projections to 2002 and 2006 (IPEA, 1997; ALÉM et GIAMBIAGI, 1997). The alternative scenario allows for a reduction in physical terms of the need to export[9] and a moderated capital-output ratio evolution[10].

Before the results of the model are presented, the hypotheses that determines them are discussed. The basic idea of building an alternative scenario is to change only a few of these hypotheses, so as to show how a few specific actions can bring socio-economic gains in terms of the chosen indicators.

The analysis presented here will be limited to some alternative technological options on which Brazil benefits from experience, know-how, assets, expertise and potentials.

III-1. Main hypotheses

The annual economic growth rate is the same in both the business-as-usual and the alternative scenarios: 5% GDP yearly increase at the 1995 price level.

Table 1 illustrates the main macro-economic assumptions made in the scenarios. GDP, imports rate (M/GDP) and government demand ($G = C_G + I_G$) are the same in the two scenarios. Meanwhile, exports (X) and investment-output ratio (k) vary from one scenario to the other. In the

[9] The slackening of the export constraint is obtained thanks to lower financial costs and to higher prices of export products if they are more elaborated and present better environmental quality.

[10] Due to the improvement in capital efficiency and the decentralisation of production toward small and medium-sized cities where investment costs in infrastructure are lower than in big cities (ALVIM, 1996).

BAU scenario, we extrapolate k to 2010, from the value estimated by the government for 2002 (1.2). In the alternative scenario, this ratio is held under 1.2 until 2010.

Table 1. Macro-economic assumptions: annual growth rates between 1995 and 2010

Scenario	GDP	C_G	I_G	X	κ
BAU	5%	3%	8%	10%	1.5
Alternative	5%	3%	8%	6%	1.2

For each good and service, a basic need constraint is set. Total exports growth rate is estimated at 10% per year. The annual growth rate of exports is set at 10% in the BAU scenario and is limited to 6% in the alternative scenario. The economy will not need to export so much, thanks to more advantageous project financing, with a better consideration of environmental parameters. This financing comes from cleaner products[11] henceforth supplied. It would guarantee the stabilisation of the relative prices of these cleaner goods, allowing a reduction in export needs in physical terms.

Table 2. Market share and asymptotes in metallurgy in terms of useful energy

year	Coke	Charcoal
1990	20%	19%
1991	23%	16%
1992	23%	14%
1993	23%	15%
1994	24%	15%
1995	24%	14%
BAU		
Minimal	15%	5%
Maximal	35%	35%
Alternative		
Minimal	15%	13%
Maximal	25%	35%

The development of small and medium towns in an alternative scenario is in part associated with better exploitation of agricultural activities, for instance with biofuel and charcoal productions, for transports and metallurgy respectively, as well as for the internal need for energy of the agricultural sector.

On the other hand, in a scenario with more international trade (an economy that is more open, more competition, etc.) the need for transport will be greater.

Even if non-competitive in the long term, biomass for energy can generate socio-economic gains in the short- to medium-run, from the exploitation of local abundant resources (labour, land, natural resources, know-how, technology, etc.), with little need for scarce resources (capital). In this way, experiences on the development of technologies appropriate within the Brazilian context are highlighted. The basic idea here is to benefit from lock-in effects (learning, acceptability) and allow diffusion through all social classes.

[11] Products are clean products when produced and used.

Assumptions at the techno-economic level play a role on the speed of some tendencies, mostly with respect to the market share. The most important behavioural changes are made in two sectors. In metallurgy, we limit the speed of coke penetration by reducing its upper asymptote. On the other hand, we raise the lower charcoal asymptote, which means a slow decline of this energy source in metallurgy. Data on the replacement of charcoal by coke in metallurgy during the 90s are presented in Table II.

With respect to household consumption, we assume that biofuel consumption will decline toward zero in the BAU scenario. In the alternative scenario, we assume that the market share of biofuel consumption will come back to the level reached at the end of the 80s when biofuels represented 50% of total household fuel consumption. These are the main changes between the two scenarios.

III-2. Results

Changes in hypotheses in the alternative scenario aim at an improvement in the well-being of the population. In this scenario, the constraint on household consumption foreseen by the government is relieved thanks to the reduction in the surplus transferred overseas and to the reduction in investment needs. The quality of life is also improved thanks to the use of renewable energy sources as opposed to that of fossil fuels.

Table 3. Household consumption in 1995 Reais (R$)

	Initial	BAU	Alternative
Agriculture	29 631 549	47 865 747	56 172 703
Industry	183 475 174	323 538 084	363 014 230
Biofuels	3 202 368	965 367	16 306 174
Combustibles	11 886 008	29 417 292	18 224 591
Electricity	10 535 543	20 572 857	23 383 411
Transports	12 533 982	23 319 905	24 141 370
Services	147 084 290	280 539 450	315 071 620
Total	398 348 914	726 218 702	816 314 099
GDP shares	60%	53%	59%

Table III shows aggregate results for household consumption of the eight goods and services in 1995 (base year) and in 2010 (BAU and alternative scenarios) at 1995 price levels. It grows at a rate of 4.1% per year in the BAU scenario, and 4.9% per year in the alternative scenario. The share of household consumption in the GDP diminish in 2010 in relation to 1995 because GDP grows at 5% per year in both scenario, a higher rate than household consumption.

The other important point concerns employment. We take the annual growth rate of the labour force estimated by the government at 2.3%. In the BAU scenario, we find an unemployment rate of 6.5%. The labour productivity trend in services is estimated so that the unemployment rate in the BAU scenario is the one observed in 1995. In the alternative scenario, we observe a fall in the unemployment rate (4.7%) in relation to that in the BAU scenario.

In the BAU scenario, it can be observed that industry and transport generate more employment, while in agriculture, the employment level does not decrease much compared with the alternative scenario, thanks to exports (see Table IV).

Some important variations are to be seen in the share of gross profits allocated to consumption[12]. Table V shows the allocation of gross profit in 1995 and in 2010 (BAU and alternative sce-

[12] We consider that wages are fully allocated to household consumption and investment and that a part of these household consumption and investment is financed by gross profits.

narios). The values indicate that household consumption is limited in the BAU scenario. This would be in even greater contrast to the reduced import rates advocated by the government.[13]

Table 4. Employment by activity sector, by revenue class (en billion units)

	A	I	B	F	C	E	T	S	total
BAU	21 551	16 656	9	50	63	210	3 727	43 774	86 040
Class 1	20 391	6 888	3	20	25	84	1 974	23 167	52 553
Class 2	1 032	8 468	4	23	33	95	1 491	16 963	28 108
Class 3	127	1 300	1	7	6	31	262	3 644	5 378
Alternative	21 972	15 532	83	42	54	221	3 382	46 257	87 544
Class 1	20 790	6 423	33	17	21	89	1 791	24 481	53 646
Class 2	1 053	7 897	43	19	28	100	1 353	17 925	28 416
Class 3	130	1 212	8	6	5	32	238	3 851	5 482

Table 5. Shares of gross profit allocated to final consumption

Initial	BAU	Alternative
60,7 %	49,7 %	66,9 %

Table 5. Final energy consumption (Mtoe) in 2010

	Coal	Oil	Gas	Electricity	Biomass	Total
BAU						
Total	21	138	23	150	65	398
M	20	5.1	2.1	35	3.8	66
O	1.1	41	17	51	49	159
T	0	73	0.5	0.8	1.0	76
S	0	1.5	0.4	24	0.2	27
H	0	8.1	2.4	33	8.4	51
A	0	9.8	0	5.9	3.0	19
Alternative						
Total	15	123	22	152	84	398
M	14	5.0	2.0	35	7.6	63
O	1.1	39	16	48	46	151
T	0	59	0.6	0.7	17	77
S	0	1.6	0.5	26	0.2	28
H	0	9.2	2.7	37	9.6	58
A	0	9.7	0	5.9	3.8	19

M = metallurgy; O = other industries; T = transports; S = services; H = household; A = agriculture

It is important to observe that there is a structural change when we compare the two scenarios. In the BAU scenario, the industry and transport shares in total value-added are higher than those in the alternative scenario. The industry energy consumption in the BAU scenario is about

[13] For 2002, the government projects a 4.2% GNP growth (reference scenario) and a 2.7% household consumption growth rate.

5% higher than that in the alternative scenario. The biomass consumption of other industries is lower by 5% in the alternative scenario, because of the activity effect. However, it doubles in metallurgy because of the substitution effect (biomass for coke).

Transport sector energy consumption is higher in the alternative scenario due to the increase in the individual transport demand which is stimulated by a higher household budget. Results for final energy consumption are presented in Table V.

Finally, CO_2 emissions in 2010 are presented in Table VI. These results show that for the same levels of energy consumption, CO_2 emissions are lower by 13% in the alternative scenario than in the BAU scenario.

Table 6. CO_2 Emissions (MtC) in 2010

	Coal	Oil	Gas	Total
Alternative	42.8	125.1	32.9	200.7
BAU	33.5	111.2	32.5	177.2

Conclusions

In order to elaborate sustainable development scenarios and identify the role of bio-energies therein, the dissociation of energy demand and economic growth must be examined, as well as factors that might intensify the phenomenon. An analysis of these factors -energy efficiency improvements and structural determinants of energy needs- requires a dis-aggregated representation of technical systems and consumption modes. Some factors are macro-economic variables, whose respective roles need to be specified, thanks to regression on past years but also on one or more future years when experts can provide a sufficiently complete set of quantified anticipations. But then, if simple extrapolations are used to determine the evolution of the energy demand, macro-economic variables remain strictly upwards. The feed-back influence on the economic activity of energy demand and of its allocation between energy chains is then ignored. For instance, this would ignore consideration of activity surplus that the energy sector could provide to the agriculture sector when a large-scale energy production from biomass is encouraged by a new environmental policy measure in the energy sector.

Facing this limitation, the answer given in top-down macro-econometric approaches is to resort to the econometric calibration of relations between economic aggregates as an internal consistency principle. Technology (respectively, consumption) basket is described in terms of cost functions (resp. budget allocation functions) that approximate 'real' production functions (resp. consumption functions) as their respective dual forms. This procedure for approximation provides substitution elasticities that are not valid but locally, close to the optimum. However, when the focus point of the study of energy demand is precisely the identification of sub-optimalities providing margins of freedom for and legitimacy to wilful policies, it is not satisfying to rely on the assumption that the system is close to the optimum.

For our model to ensure whole economic consistency in the projected energy balance, we associated it with the projection of an I-O matrix of the economy. The I-O matrix allows for an analysis by products (including energy products) of the production activities and its uses, as well as for an analysis by production branch and the corresponding uses of production factors (including agricultural products).

Values resulting from the projection of the energy balance are used for the projection of the I-O table and reciprocally, by iteration. The model is closed with the mechanism through which economic aggregates depend on energy choices.

We showed the technical feasibility of the two types of modern biomass developed and experimented with for Brazil. In the alternative scenario, metallurgy employs more charcoal (3.8 Mtoe or 6 Mt) than in the BAU scenario.[14]

To produce the 16 additional Mtoe of biofuels for transports in the alternative scenario, it is necessary to exploit 3,6 millions hectares.[15] This activity would offer employment to 360 thousand families or to almost 20% of the population estimated at 9.3 million[16] in the CMP in 2010 (6).

The socio-economic and environmental gains in the alternative scenario are remarkable. These gains were obtained by making a few small changes, notably reductions in investment and export needs at the macro-economic level and the exploitation of some renewable energy sources at the techno-economic level. The gains for society, in terms of increased household consumption (12.4%), reduced CO_2 emissions (13.3%) and reduced unemployment rate (of 6.5% to 4.7%), are considerable.

For a same GDP, the combination of a greater household consumption and less CO_2 emissions in the alternative scenario suggests that there would be an improvement in the well-being in the alternative scenario compared with that in the BAU scenario. The human and social development of the country is in some way identified through the real possibilities of income redistribution by means of a strategy that develops activities in countries and aims at a reduction in some spatial disparities.

In the Brazilian case studied here, we have not tackled with the issue of the public incentives necessary to promote bio-energies. However it is well acknowledged that biomass viability from a micro-economic point of view requires the elimination of some market imperfections. For instance, biomass could become competitive if carbon had a price or if financial contributions to biomass were available in an international market. This should be possible with the adoption by the United Nations Climate Change Convention Framework (UNCCCF) of economic instruments such as tradable permits and clean development mechanism. For the time being in the context of international negotiations for climate change mitigation, Brazil does not belong to the Annex I countries that are committing themselves to climate policies but the appropriate mechanisms may emerge with the creation of a market for carbon credits.

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References

[1] ALÉM, Ana Cláudia e Fabio GIAMBIAGI, (1997), « O aumento do investimento : o desafio de elevar a poupança privada no Brasil », *Revista BNDES*, n° 8, Rio de Janeiro.

[2] ALVIM, Carlos F. (coord.) (1996), *Brasil : O Crescimento Possível*, éd. Bertrand Brasil, Rio de Janeiro.

[3] ANDRADE Maria Lúcia A. et al. (1997), "Siderurgia no Mundo", *BNDES setorial n° 5*, Rio de Janeiro, March.

[4] ANDRADE Adnei, Carlos ANDRADE and Albert BODINAUD (1998), "Biomass energy use in Latin America : focus in Brazil", in IEA/OECD, *Biomass energy : data, analysis and trends*, Paris, 23-24 March, pp. 87-95.

[5] BIRD (1994), *O Pólo Siderúrgico de Carajás : perspectivas, opções energéticas e gestão ambiental*, Draft, October.

[14] Charcoal production potential in only the Carajás Metallurgy Pole (CPM) in the Amazon region is 134 Mt per year (See, COSTA, 2000).

[15] This means 24% of fallow lands in the CMP impact zone in 2010.

[16] With a mean size of 5 members per family.

[6] BÖHRINGER, Christoph (1998), « The synthesis of bottom-up and top-down in energy policy modeling », *Energy Economics*, n° 20, pp. 233-248.

[7] CIRED (1997), « NEXUS-IMACLIM : Modèle d'exploitation des scénarios de développement à long terme et d'évaluation des politiques d'environnement », Rapport final ADEME, Paris, octobre.

[8] COSTA, Ricardo Cunha da (1999), "Contraintes d'environnement global et impératifs de développement à court terme: étude des conditions d'une harmonisation dans le cas du Brésil", PhD. thesis, École des Hautes Études en Sciences Sociales, CIRED, Paris.

[9] COSTA, Ricardo C. (2000), "Sustainable Development: The Role of Biomass in Brazil", in: 1st World Conference on Biomass for Energy and Industry, pp. 163-166, Sevilla, 5-9 june.

[10] COSTA, Ricardo C. (2001), "Do model structures affect findings? Two energy consumption and CO_2 emissions scenarios for Brazil in 2010", *Energy Policy*, v. 29, pp. 777-785.

[11] COSTA, Ricardo C. and A. FALLOT (2000) "Bio-energy: different prospects when socio-economic contexts differ", *1st World Biomass Conference and Technology Exhibition* 7.25, Sevilla, june.

[12] DESTAIS, G. (1993), "Etude synthétique comparative des modèles français de prospective énergie-économie-environnement", IEPE, juillet.

[13] FALLOT, Abigaïl (2000), "Innovation dans le secteur énergétique sous contrainte d'objectifs publics : le cas de la biomasse", Thèse de doctorat, Analyse et Politique Economiques, EHESS, avril.

[14] HOURCADE, J.-C. (1996), « Estimations des coûts de limitation des émissions de gaz à effet de serre », in : BRUCE, James P., LEE, Hoesung et HAITES, Erik F. (dir.), *Le Changement climatique : Dimensions économiques et sociales*, pp. 277-315, La documentation Française, Paris.

[15] IEA/OECD, *World Energy Outlook*, Paris.

[16] IPEA (1997), *O Brasil na virada do milênio : Trajetória do crescimento e desafios do desenvolvimento*, vol. 1, Rio de Janeiro.

[17] GRUBB, Michael et al. (1993), "The costs of limiting fossil-fuel CO_2 emissions: A survey and analysis", *Annual Review Energy Environment*, 18:397-478.

[18] REIS Eustáquio J. (1996), "Os impactos do pólo siderúrgico de Carajás no desflorestamento da Amazônia Brasileira", in *Perspectiva da economia brasileira 1996-1997*, IPEA, Rio de Janeiro, pp. 691-715.

[19] SILVEIRA, Semida and Maria M. MORALES (1997), "Market forces alone will not contribute to emissions reduction – the case of the iron and steel industry in Brazil", *Renewable Energy for Development*, vol. 19, n°3, December.

[20] SHUKLA, P. R. (1995), « Greenhouse gas models and abatement costs for developing nations : A critical assessment », *Energy Policy*, vol. 23, n° 8, pp. 677-687.