Building Input-Output tables in physical units and in money value to calibrate hybrid energy-economy CGE models: application to the Brazilian economy

Julien Lefevre[1]

Abstract

This paper describes a methodology to make consistent economic data (national accounts) and data from "material" balances (energy balances, etc) in order to calibrate energy-environment-economy CGE models. The difficulties often underestimated in existing models to combine those data bases, push for reexamining the theory governing the description of the economic flows both in monetary value and in "physical" volumes. It results in an innovative process of *hybridization* of data which consists in relying on material flows and data on prices to delimit the cycle of material goods within the entire economic system without modifying the size of the economy. We apply the protocol in the last section to build a *hybridized* Input-Output table with 16 sectors for Brazil in 2005.

Key words: hybrid modeling, hybridization, Input-output tables, energy balances

Introduction

For a few years, some specialists of Economy-Energy-Environment modeling have called for the development of so called "hybrid" models that actually describe simultaneously physical flows and monetary flows in an economy (Hourcade et al. 2006).

This plea is the result of recurring debates between bottom-up and top-down models. The first approach provides a detailed description of technologies but works in a given economic environment without taking into account the economic consequences of public policies designed to initiate technological changes. The second captures the relations between economic flows but at the cost of a weak representation of technical systems. Certainly, as pointed out by the second IPCC report (SAR, 1995), the border between the two approaches tends to become blurred but the diagnosis given by Edmonds and Grubb (Grubb et al. 1993) on the need and the difficulties of dialogue between engineers and economists remain broadly valid.

A major obstacle to such a dialogue is the current lack of accounting systems that facilitate the consistent inclusion of economic flows, energy and "material" flows of an economy at a given date. This paper presents a methodology that makes it possible to build such accounting systems for national economies despite the difficulty of lacking data.

After having briefly recalled the theoretical and methodological justifications of hybrid accounting systems, we detail the principles of construction of such accounting systems, before describing a systematic "hybridization process" that we illustrate in the case of Brazil.

[1] CIRED (jlefevre@centre-cired.fr)

1. The origin of hybridization of accounting matrices: back to Arrow-Debreu axiomatic

The debates on energy and climate policies assessment have been well fed by the historical opposition between engineers and economists. Adopting a bottom-up approach, engineers have studied the competition in partial equilibrium between energy technologies. This requires to explicitly accounting for the physical resources of primary fuels and describing the technical and economic constraints of supply and demand for final energy[2]. Thus engineers analyze climate policies through the lens of technologies and usually represent the reactions of technical systems to exogenous shocks on energy prices in order to estimate the volume of investments needed. In the meantime the limits of those models are rather obvious and assumed by their designers. They certainly can embark macroeconomic scenarios driving energy demand levels (value-added, household's income, etc) and energy prices paths. However, they lack the retroaction loops of the impacts of technical change in the energy system on the global economy (final energy prices variations and propagation, crowding out effect of investments in the energy system, retroaction of technical progress on demand, etc). Such general equilibrium effects are captured by top-down models in the view to assess the impacts of energy and climate policies on global economic activity, employment, competitiveness, etc.

The limits of top-down models are less easy to grasp. Whether it be well aggregated frameworks (MACRO model) or models with numerous sectors (GREEN (Burniaux et al., 1991), EPPA (Paltsev et al., 2005)), such modeling tools are supposed to project economies supported by some "physical" and technical content. Nonetheless, those models do not rely on any engineering knowledge to capture this physical content. The ladder is to some extent "subrogated" through the representation of the relationships between physical equipment, intermediary consumptions (including energy) and labor with a macroeconomic production function instead of relying on engineering functions. This wide usage of the production function has been a methodological reflex found in the standard "toolbox" of CGE modelers since the boom of numerical calculation capacities in the late eighties.

This method is based on what Solow's calls a mathematical "wrinkle". This consists in choosing first a mathematically tractable function (Cobb-Douglas, CES, Translog or mixed solutions[3]) that sets a priori (once and for all most of the time) the shape of technical substitution possibilities among production factors. Then final technical substitution possibilities plus future demands for production factors according to their relative prices are simultaneously and (and heroically) deduced from the initial cost shares of primary and secondary production factors as it appears in national accounts. This wrinkle relies on extensions of the theorem of the envelop (Shephard Lemma and Roy identity) which implicitly suppose the strong assumptions of perfect markets and agents cost minimizing programs at calibration year and along the economic path. And Solow himself warns about any interpretation of the production function in terms of technical content:

Such a convenient method to describe technical possibilities (meanwhile prescribing automatically restrictive first-best behaviors) is actually well remote from an engineer point of view. At the limit, we are not sure that reacting to very high prices compared to the baseline such functions do not describe technical systems that break thermodynamic laws. (McFarland, 2004).

[2] Cost of technologies, thermodynamic efficiencies of processes, etc
[3] Nested CES-Leontief (EPPA)

To take only one example, from an engineer point of view, the substitution between for instance oil and gas to provide a given energy service will be described by a substitution between identified technologies. The ratio of substitution oil-gas (the number of additional units of gas to replace one unit of oil no longer consumed) will depend on the relative efficiency of technologies to provide the final energy service and on constraints on equipment change. With a classical production function, the substitution usually works with a given elasticity linking rates of substitution of fuel ratios to rates of variation of prices ratios. This way the ratio of substitution in quantities will depend on initial shares of oil and gas which seems a very particular case supported by no technical background.

Moreover the production function with a constant elasticity of substitution between two factors cannot embark effects of irregularity and threshold (like technical asymptotes) that exist in real technical systems and that can be crucial for climate policy assessment (see Ghersi and Hourcade, 2006).

Beyond the representation of technical possibilities, this approach fails in describing accordingly the whole “material” content of future growth. In spite of undeniable progress made in the representation of endogenous capital accumulation and efficiency gains in top-down recursive models, modelers stumble on the problem of fixed envelop of possibilities (defined by the fixed elasticities of substitution) to describe relevant technical progress and the articulation of technical progress (in the energy system in particular) and the global structural change. Furthermore such representations become doubtable when simulating violent shocks on energy prices over the long run or very ambitious climate policies (such as French “facteur quatre”) because it implies massive investment reorientations, land-use changes, consumption patterns evolution and global structural changes.

This persistent approach must have something to deal with the success of Manne and Rutherford’s metaphor of the elephant and rabbit‘s stew: what happens in the energy system (which represents a small part of the GDP) does not have a significant impact on the whole economy. It had been formulated to justify the coupling of ETA (model of energy sector) and MACRO (macroeconomic module) which is one of the first attempts to build a “hybrid” model. However, the supposed small impact of the energy sector on the whole economy is obviously questionable when we look for instance at the effects on the economy over the short and long run of high oil prices (Jones et Leiby, 1996). Moreover such attempts of coupling do not give insights on intersectoral dynamics and on global trade.

Numerous attempts of hybridizing models can be found with the view to bridge some of the gaps previously introduced but those tries are usually based on already existing modeling tools without building a “hybrid” framework in its foundation (see soft link/hard link distinction of Böhringer (Böhringer, 2008)).

Therefore, facing the limitations previously explained, we propose here an attempt to re-establish the conditions of control at the interface between economic and technical systems. That for it is needed to go back to the first interpretation of Arrow-Debreu axiomatic which sets the concept of general equilibrium and the dual characterization of economic objects (in physical volume and in monetary value linked by a price). The idea of general equilibrium does not refer here to any hypothesis on economic behaviors (perfect markets, etc). It simply supposes that there is a simultaneous equilibrium of tangible physical flows and monetary flows and a coherence volumes-value through a real price system. Such a scheme makes it possible in modeling exercises to ensure that the projected economy is supported by a realistic technical background (in the engineering sense) and, conversely, that projected technical systems correspond to realistic economic flows and consistent sets of relative prices. Some CGE models then called “hybrid” CGE models have been developed based on this framework and are able to embark tangible physical representations from BU models (Imaclim (Sassi et al., 2010) ou le Second Generation Model (SGM) (Fawcett et Sands, 2005)).

In practice, working under this hybrid scheme requires to build a dual accounting framework in real physical quantities and in monetary values by superposing then combining macroeconomic tables in monetary value and balances of physical flows (such as energy balances) and to link them to a common set of material indicators (spatial indicators, distances, etc).

This kind of work was yesterday limited by difficulties of data availability and computational constraints. But current data availability with desegregated sectors, computational capacities and methods to estimate missing data make it possible today to bring operational what used to be costly to achieve.

2. Principles and stakes of the “hybridization”process

The hybridization process consists in a set of manipulations on data that makes it possible to bring consistency between data from national accounts and data from “material” balances and physical indicators. It results in a hybridized picture of the economy at base year built to calibrate hybrid CGE models.

The dual representation of economic flows both in monetary value and in physical quantities is based on two principles:

- The two parts of the description abide by the principle of conservation: each use supposes the availability of a resource and each resource has a use. This principle is similar to the conservation of mass in physics.
- Physical and monetary flows are linked by a system of prices and for each macroeconomic transaction of a material aggregate, the total corresponding monetary value is the product of volume and a relevant price.

In an economy with several sectors, those principles are summed up by the following basic system of equations:

$$\begin{cases} \forall i, & \sum_E Q_{i,E} = \sum_R Q_{i,R} & \text{Equilibres Emplois-Ressources en quantités} \\ \forall i, & \sum_E V_{i,E} = \sum_R V_{i,R} & \text{Equilibres Emplois-Ressources en valeurs} \\ \forall (i,o), & V_{i,o} = P_{i,o} * Q_{i,o} & \text{Cohérence Quantités-Valeurs} \end{cases}$$

Où Q, agregated volumes (in physical units like Mtoe)

V, monetary flows (in monetary value like €)

i, sectors/goods of the economy

o, agregated economic transactions

R, items of ressources (production, imports, etc)

E, items of uses (consumption, investments, exports, etc)

P, agregated prices linked to agregated economic operations on goods

2.1. An example: combining national Input-Output accounting tables and energy balances

Among all physical flows, energy flows can be conveniently measured with the common metric of the calorific content (expressed in Mtoe, cal, etc) and annual complete energy balance are available.

In *figure 1* are illustrated the basic principles of hybridization of physical and monetary flows of energy goods and the theoretical links between:

- Input-output accounting tables (I-O tables) that compile in monetary value the items of resources and uses of the different aggregates of goods of an economy in an Input-output logic. Columns summarize the structure of resources and distinguish intermediary consumptions (V matrix), value-added (VA) and imports (M). Rows summarize the uses of the goods with again the intermediary consumptions plus the final consumptions (households consumptions ©, public consumptions (G), Gross fixed capital formation (I), and exports (X). The balance between resources and uses is done by construction.
- Energy balances (EB) that compile annual energy flows (in Mtep) of energy transformation for final energy production and of consumption of this final energy according to the main energy sources. This statistical scheme can be turned into an input-output framework with intermediary consumption for productive sectors (including energy transformations within the energy system)(Q) and final consumption (C, X) for the uses and the volumes produced (Q) and (M) for the resources.

Achieving the framework described in *figure 1* requires overcoming a series of practical constraints that the hybridization process has been designed to solve.

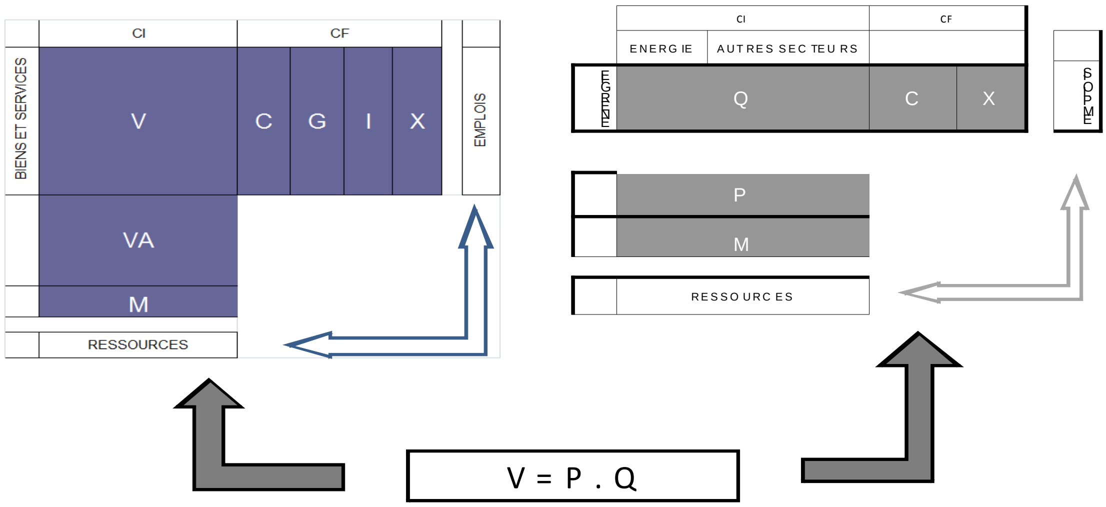

Figure 1: Equilibrium resources-uses in monetary value in the I-O table (on the left), equilibrium in physical volumes in the transformed energy balance (on the right) / Coherence quantity-value through the price system

2.2. How to deal with aggregation and heterogeneity

The challenge is here to avoid the classical pattern consisting in manipulating volumes of goods that are in fact built from economic statistics reduced with constant prices hypothesis.

From a certain point of view, monetary value is the only available aggregator of heterogeneous goods through their marginal economic value. Fixing all prices to unit makes it possible to get pseudo-quantities of goods and to study short run and medium run variations of material inputs of productive sectors according to relative "pseudo-prices" variations.

Nevertheless this convenient process does not bring the crucial control of physical quantities underlying long run analysis because they are not explicitly tracked (resources stocks, energy mix, land-use, etc). Furthermore this feature limits the use of expert-based data on technologies. (EPPA, 2005)

The alternative is to use real physical quantities in the analysis. For energy goods, the calorific content is a convenient and widely used metric along with extensive available database. Having for example energy quantities of coal and gas involved in electricity generation plus the relative yields of technologies makes it possible to represent the competition between coal and gas for electricity generation over the long run according to engineering expertise[4]. Meanwhile, one can keep track in a straightforward way of carbon emissions of sectors according to tracked energy consumption s and the carbon content of energy fuels. Metrics based on calorific content are also available for agricultural commodities for which one can use food calories.[5]

Beyond, the only metric available is the mass which can be a relevant indicator for the main basic industrial commodities: cement, steel, paper, aluminum, etc. Quickly the physical and economic heterogeneity of goods becomes a problem. At this stage some proxies can be used for some others goods but eventually the accounting framework will obviously have to be closed with a composite

[4] What adaptation of scale, mechanisms of learning, technical asymptotes as well as second-best empirical behaviors?
[5] (Dorin et Le Cotty, 2010)

sector with pseudo-volumes indicators. The level of aggregation of the composite good depends on the modeling objectives.

2.3. Constraint linked to nomenclature

Furthermore, using physical indicators becomes highly relevant when we understand the alternative insights from the I-o table it can provide on the cycle of material goods within the economy. Such insights are actually brought by the gaps that can be revealed between national accounts and material balances.

Sources of imperfection are numerous in accounting balances because of numerous adjustments needed to get consistent tables with equilibriums between resources and uses. Moreover national accounts and material balances such as energy balances are built by different communities of statisticians with different methods and nomenclatures. As a result, the superposition of energy balances and macroeconomic Input-output tables without more caution gives generally a hybrid system with irrelevant prices of energy goods.

Taking the example of Brazil for the year 2005, the total economic value of *petroleum energy products* is estimated to represent 167 billion R$ once data from energy balance have been multiplied by observed prices. This has to be compared to the 188 billion R$ for *petroleum products* (often wrongly identified as *petroleum energy products* in models) in national accounts. In France for 2004, petroleum fuels are estimated to represent 67.5 billion Euros versus 93 billion Euros for petroleum products from INSEE.

The main reason for those gaps is a difference of nomenclature between energy balances and national accounts that can only be solved with the alternative use of physical quantities.

Indeed, the content of energy goods aggregates in national accounts is generally different from the energy products one want to isolate for the analysis. In the case of Brazil, if we look at the exact nomenclature, the aggregate called "petroleum products" includes beyond petroleum fuels, nuclear combustibles, and refined products used as inputs for non energy purposes with very different value added (tar, solvent, etc).

Thus if we keep this kind of level of aggregation without more precaution to estimate the value added of petroleum fuels, we get an overestimation of their average economic value (+ 13% and + 38% in the examples above) when dividing the value added by the quantity given by the energy balance. And there is reasons to think such substantive biases must have impacts on modeling results and climate policy analysis.

Therefore, crossing national accounts with physical balances makes it possible to highlight some nomenclature gaps and to correct some economic flows according to their material content. Moreover in certain case, relying on energy quantities is also the only trustable way to split certain energy aggregate of national accounts in order to isolate the energy flows that count for climate and energy policies analysis. [6]

[6] In most cases electricity and natural gas supply are aggregated in national accounts whereas it can be crucial to isolate the bills and cost structure related to those two very different energy sources. Moreover, liquid

2.4. Current existing methods of "hybridization"

Let's examine how such practical constraints are treated in Energy-Economy-Environment models with a hybrid scheme and the dual description of energy goods. To our knowledge, no hybrid CGE model includes so far tangible physical flows beyond energy goods. Moreover, most hybrid models are multi-regional (EPPA[7], GEMINI-E3[8], etc) and are calibrated with GTAP databases (Global Trade Analysis Project).

GTAP releases databases initially dedicated to analyze the international trade linked to agricultural goods. Furthermore, in the energy-economy databases the constraints of consistency that statisticians strive to respect are linked to international flows. On the other hand, historically the constraints of hybridization at regional scale have been remaining secondary and the method used at regional levels varies notably between the different databases. To take only two examples, in (McDougall and Lee, 2006) the consistency between energy and economic data is brought by introducing energy prices and correcting energy value-added according to different ad hoc rules. In GTAP 5.0, (Sands, 2005) reports that in the GTAP-E database the adjustments operated bring apparent problematic biases: the value-added of the electricity sector in China (2007) is divided by two compared to primary statistics and the total domestic coal production (the first primary resource) is 50% higher in volume than in the initial energy balance.

Starting from those observations, the designers of the former *Second Generation Model* (SGM, today Phoenix model) (Fawcett, 2005) elaborated a simple method of hybridization. Through this method, the coherence between values and energy quantities is guaranteed by the calculation of a unique average price by energy good starting from the values of the accounting matrix and the quantities of the energy balance. This vector of energy prices of size n (number of energy goods) is simply calculated by solving the system of n linear equations of equilibrium between resources and uses of the n energy goods. This treatment makes it possible to preserve both the value-added of the different energy sectors – as it appears in national accounts – and the physical volumes published in energy balances.

Nevertheless this method presents at least two limitations:

- First it assumes a unique price of consumption for a given energy aggregate for all the different consuming agents whereas there is in practice a big heterogeneity of tariffs. This leads to mislead the split of the total energy bill of the economy between productive sectors and households. Meanwhile there is a large available information on energy tariffs heterogeneity.
- Second this method cannot solve the problems of aggregation levels, of the right economic value of energy aggregates and all the crucial question of nomenclature gaps (see 2-d). Because this process sets once and for all the value-added of energy goods according to national accounts with no possibility to examine the nomenclature gaps formerly identified.

---

petroleum fuels are rarely isolated from other non-energetic petroleum products whereas only the economic value of the formers counts in climate and energy policy assessment.

[7] Paltsev et al., 2005

[8] Labriet et al., 2010

The result is a global overestimation of energy prices consistent with generally overestimated value-added.

3. A methodology of hybridization of energy flows

Last section has enhanced current underestimations of the difficulties around the hybridization process. The challenge is thus to elaborate a methodology to produce a hybrid I-O matrix that respects the two fundamental constraints (see section 2-a) without altering primary statistics that count for climate policy analysis (physical energy flows, energy prices on the one hand, size and content of the economy on the other hand).

The method we propose reaches such goals and facilitates the description of the physical content of the economy meanwhile favoring the inclusion and synthesis of information of varied sources. It is designed to be easily adapted to all regional specificities and related to the type of research question.

The method starts from the systematic comparison of nomenclature between physical statistics and national accounts. This comparison makes it possible to identify the gaps between the description of economic flows in the national accounts and their counterpart in material balances. Once the flow in monetary value respective to a given good has been rebuilt based on physical data, the gap in monetary value is switched to composite goods and services not to modify the size of the economy (the level of GDP given by national accounts for instance).

In order to do the quantitative switches, we use the material balances and data on observed prices with the view to rebuild the material bills of the economy. The differences in monetary value between the levels of consumed goods as it appears in the original I-O matrix and the newly calculated material bills are allocated by construction to non material goods. Eventually those economic flows are logically added to composite non-material goods.

To the extent that the energy balances are almost the only extensive available databases in a standard format, we describe in the following of the paper a standard methodology of hybridization of energy goods. The hybridization of agricultural and industrial goods would follow the same scheme according to the datasets available.

Technically, the hybridization process needs 3 steps:

- Build an Input-output table in energy flows (Mtep)
- Build a table of observed prices (each price is the average observed price related to the operation of final production-circulation-consumption of an energy good according to the nomenclature chosen) and calculate an I-O table in monetary value (energy bill) by multiplying the matrix in prices and energy flows term by term.
- Incorporate this new energy bill in the original I-O table which supposes to rearrange the nomenclatures and formulate some hypothesis on the cost structure and valued-added of energy goods

Conclusion

This paper aimed at presenting a methodology to make consistent economic data from national accounts and data from "material" balances in order to get a consistent picture of an economy with the view to calibrate energy-environment-economy CGE models.

Its main strength is to precisely delimit the circuit of energy and material goods within the economic system. The method relies on the combination of data on physical flows and observed prices that makes it possible to isolate specific economic circuits that count for the analysis of climate policies.

The dialogue between accountants and engineers is favored by the freedom of inclusion of disparate sectoral data necessary to build the hybrid input-output scheme. In particular, this method ensures the ability to disaggregate sectors at will according to their physical nature but also allows great flexibility in describing the role of these material aggregates in the "monetary" sphere. Indeed we have showed how we could impose tariffs differences for energy goods as well as specificities on the cost structure of the energy aggregates concerning production factors (inputs, labor, capital), taxes and margins in coherence with these price levels.

Altogether this approach provides a great control of material cycle at the macro level, based on a deep understanding and mastery of flows at the meso or micro level. We are firmly of the opinion that this can give a better robustness of the economic analysis of specific policies that impact these circuits (a carbon tax on fossil fuels for example, (Ghersi, 2009)).

Eventually, the practical example presented on the energy sector can be generalized to other types of material flows such as heavy industrial goods (steel, cement, paper, etc.) or agricultural commodities. This procedure may also involve other types of indicators such as surfaces or distances for spatial analysis (urban economy, land-use models).

References

Arrow K.J. et Debreu G., 1954. "Existence of an Equilibrium for a Competitive Economy". *Econometrica*.

Babiker, M.H.M. and Reilly, J.M. and Mayer, M. and Eckaus, R.S. and Sue Wing, I. and Hyman, R.C., 2001. "The MIT emissions prediction and policy analysis (EPPA) model: revisions, sensitivities, and comparisons of results". *MIT Joint Program on the Science and Policy of Global Change.*

Böhringer, C., Rutherford, T. F., 2008, "Combining bottom-up and top-down", *Energy Economics*, 30, 547-596

Brunelle T., Souty F. , Dorin B. , Le Cotty T., Dumas P., Ciais P. : « A New Land Use Modelling Architecture : The Nexus Land Use ». Communication pour conférence internationale des économistes de l'énergie l'IAEE (6-9juin 2010), Montreal.

Burniaux J. M., Martin, J. P., Nicoletti, G., Oliveira Martins, J., 1991, "GREEN - A Multi-Region Dynamic General Equilibrium Model for Quantifying the Costs of Curbing CO2 Emissions: A Technical Manual", OECD
Economics Department Working Papers 104, OECD Economics Department

Capros, P. and Mantzos, L. and Kolokotsas, D. and Ioannou, N. and Georgakopoulos, T. and Filippopoulitis, A. and Antoniou, Y.}, 1998 The PRIMES energy system model--reference manual National Technical University of Athens, Document as Peer Reviewed by the European Commission, Directorate General for Research

Crassous R., 2008. « Modéliser le long terme dans un monde de second rang: Application aux politiques climatiques ». *Thèse de doctorat*.

Dorin B., Le Cotty T.**,** 2010. In : Paillard Sandrine (ed.), Treyer Sébastien (ed.), Dorin Bruno (ed.). *Agrimonde. Scénarios et défis pour nourrir le monde en 2050*. Versailles : Ed. Quae, p. 25-54. (Matière à décider !).

Eggleston, S. and Buendia, L. and Miwa, K. and Ngara, T. and Tanabe, K, 2006. "IPCC guidelines for national greenhouse gas inventories". *Institute for Global Environmental Strategies, Hayama, Japan.*

Eurostat Manual of Supply, Use and Input-Output Tables , 2008.

Fawcett, A.A. and Sands, R.D., 2005. "The Second Generation Model: Model Description and Theory". *Pacific Northwest National Laboratory*, PNNL-15432.

Fishbone, L.G. and Abilock, H., 1981. "Markal, a linear-programming model for energy systems analysis: Technical description of the bnl version". *International journal of Energy research.*

Ghersi F., Hourcade JC., Combet E., 2009. "Taxe carbone, une mesure socialement régressive ? Vrais problèmes et faux débats". WP CIRED.

Grubb, M. and Edmonds, J. and Ten Brink, P. and Morrison, M., 1993. The costs of limiting fossil-fuel CO2 emissions: a survey and analysis. Annual Review of Energy and the environment}

Haurie, A. and Kanudia, A. and Loulou, R.and M. Labriet and L. Drouet and M. Vielle, 2010. "Coupled Bottom-Up and Top-Down Modelling to Investigate Cooperative Climate Policies".

Hourcade, J.C., Jaccard, M., Bataille, C., Ghersi, F., 2006, "Introduction to the Special Issue of the energy journal", *The Energy Journal,* Special Issue: *Hybrid modelling of energy environment policies: reconciling bottom-up and top-down*

Lee, H. and Oliveira-Martins, J. and Van der Mensbrugghe, D. and Organisation for Economic Co-operation and Development, 1994. "The OECD Green model: an updated overview" *Organisation for Economic Co-operation and Development.*

McDougall, R. and Lee, H.L.}, 2006. "An energy data base for GTAP". *Global Trade, Assistance and Production: The GTAP 6 Data Base*.

McFarland, J.R., J.M. Reilly, and H.J. Herzog (2004). "Representing
Energy Technologies in Top-Down Economic Models Using Bottom-Up Information".
Energy Economics **26**(4): 685-707.

Sergey Paltsev, John M. Reilly, Henry D. Jacoby, Richard S. Eckaus, James McFarland, Marcus Sarofim, Malcolm Asadoorian and Mustafa Babiker,2005. The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4

Sands, R.D. and Miller, S. and Kim, M.K, 2005. "The second generation model: Comparison of SGM and GTAP approaches to data development". *PNNL report*, volume: 15467.

Sassi, O. and Crassous, R. and Hourcade, J.C. and Gitz, V. and Waisman, H. and Guivarch, C., 2010. "Imaclim-R: a modelling framework to simulate sustainable development pathways". *International Journal of Global Environmental Issues* 10(1): 5-24.

Schrattenholzer L., 1994. "The energy supply model MESSAGE". *IIASA.*

Solow, R.M. , 1988. "Growth Theory and After." *American Economic Review* 78(3): 307-317.