Construction of hybrid Input-Output tables for E3 CGE model calibration and consequences on energy policy analysis

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Abstract

"Hybrid" modelling approaches are increasingly used to bridge the historical gap between the bottom-up and top-down approaches to energy/economy/environment modelling. By nature, they require a substantial effort of harmonisation between national accounts and energy balance data. However, the methods applied for reconciling those data and their impacts on the empirical information used to calibrate CGE models are generally poorly documented, if at all, even for prominent models. Different hybridisation techniques have different impacts on key empirical features that are important for policy evaluation. After reviewing the literature on hybridisation methods, this paper proposes and details an innovative procedure for building hybrid Input-Output matrices at the country scale, and illustrates it with data for France. Compared to existing methods, this procedure includes information about energy flows, prices and quantities coming from energy statistics, without alteration, within a consistent social accounting framework. The impact of this method is illustrated in a small CGE model that does not incorporate the other modelling specificities of hybrid models. The welfare costs of a same price-induced energy policy are evaluated keeping the same behavioural structural assumptions and parameters, but with a calibration of the model on our hybrid matrices, or alternatively, on unmodified input-output data. This comparison shows the importance of describing with transparency the impacts of data hybridisation methods.

1 Introduction

Much compared and commented upon at the end of last century, both bottom-up and top-down approaches to Energy-Economy-Environment (E3) modelling have known limits. On the one hand, engineering analyses focused on the representation of technologies do not account for the feedback loops between the energy systems and the rest of the economy; on the other hand, traditional economic modelling is ill-equipped to embark even abstract descriptions of the inertias and flexibilities of the complex technical systems underlying energy consumptions. In the last decade, the E3 modelling community has increasingly tended to overtake these limits by developing "hybrid" models (Hourcade et al. 2006). Notwithstanding their precise modelling choices, hybrid models should by nature rely on benchmark databases that provide dual information on the economic flows in monetary value and in physical units, notably for energy goods—the necessary condition to control the interface between economic and technical systems.

Unfortunately, matrices that consistently accommodate monetary and physical flows are still rarely available from statistical agencies—although the ongoing developments of satellite accounts to the System of National Accounts (SNA) are promising (United Nations et al. 2003). Beyond hybrid flow accounts, existing data on the underlying price system must also be acknowledged, and should be incorporated in any dataset providing the calibration material of hybrid models. However, most hybrid modellers are regretfully elusive about how they build such datasets from the raw data, *i.e.* the series of trade-offs and assumptions that they unavoidably make to reach consistency or fill statistical gaps. The leeway in these trade-offs and assumptions potentially leads to benchmark databases with contrasted descriptions of the energy content of the economy. Paramount elements like the value of energy flows, the share of firms and households in physical energy consumption, and the different energy purchasing prices faced by agents, may vary, and therefore, may impact the evaluation of the general equilibrium consequences of energy policies.

This paper focuses on the impacts of hybridisation techniques on the empirical description of an initial state of the economy used to calibrate all hybrid computable general equilibrium (CGE) models of one country. Thus, we do not provide here a discussion of the various methods used for modelling technical change in those models, even though innovations in this area constitute the primary motivation for developing hybrid CGE models. Our first main objective is to show the importance of making explicit this procedure of data treatment in order to better identify the empirical uncertainties associated with the choice of data and their processing. Our second objective is to detail a hybridisation procedure that responds to the shortcomings which are identified in existing techniques. The main virtue of this methodology is to gather and keep unaltered the richness of information coming both from energy statistic and national accounts. Compared to the other documented procedures, this methodology allows in particular the description of the heterogeneity of purchasing prices paid by economic agents (each economic sectors and final consumers described). Indeed, net-of-taxes prices are assumed identical in most CGE models, although important differences are recorded in energy statistics. With respect to the evaluation of a price-induced policy, prices differences would have important impacts on the way the price system “decentralises” the price-signal policy and induces the responses of economic agents.

Our paper addresses such issues. In section 2, we review the documented efforts to combine datasets on energy prices and quantities and national accounts, and we present our original protocol to build a hybrid energy-economy Input-Output Table (IOT) at a regional scale. We illustrate this protocol with 2010 data for France. For better reading, we only present in the text a simplified version of the hybrid IOT, with high level of aggregation (only one energy sector and one non-energy sector). The technical details of the hybridisation procedure for France and the real 27-sectors table that have been built are given in appendices (section 6.1 and 6.2). In section 0, we implement a highly simplified two-sector static CGE model describing one open-economy and we calibrate it alternatively on our hybrid IOT and the standard IOT (published in national accounts). This model is based on well-known neoclassical assumptions and practices that have been used in CGE modelling to represent substitutions and macroeconomic behaviours (sub-section 3.1). We do not think that such a model is well-suited for analysing energy policies, especially when the objective is to analyse non-marginal technical changes and the long run. But we have chosen to use such a model in order to isolate the impact of data processing from the other methodological innovation of hybrid approaches, in particular the use of engineering expertise for modelling the future technical change possibilities in place of postulated aggregate production function that are parameterised with econometrically estimated elasticities. In sub-section 3.2, we explore how the hybridisation procedure, and the differences in the empirical description it entails, impacts the evaluation of the welfare costs of a basic energy conservation policy. The contrasted results offer an illustration of the consequences of hybridising benchmark data.

2 Hybrid accounting methods

Standard macroeconomic models, although based on the Arrow-Debreu paradigm—*i.e.* on a dual representation in quantities and values of the flow of goods and services in the economy—are exclusively built on monetary data drawn from national accounts, commonly synthesised in the form of a “social accounting matrix”. Benchmark quantities are not described in physical units but are deduced from the monetary data based on some exogenous set of relative production prices. Freely fixed, as only relative price variations matter to the standard macroeconomic approaches, these “prices” are often normalised to 1 at the base year for simplification. The need for physical information on underlying material flows, such as Greenhouse Gas emissions levels, to carry out E3 analysis have led to develop hybrid accounts.

Hybrid accounting systems depart from the standard accounts by collecting and processing additional data on volumes and prices from various sources and by reconciling them with the monetary flows registered in the Input Output Tables published in national accounts. To reach consistency in the hybrid description, all hybridisation procedures must reconcile data in order to meet two basic accounting principles. First, both physical and money descriptions must respect the conservation principle (the balances of resources and uses, both in quantities and values). Second, physical and money flows are linked by a unique system of prices: the economic values associated to the production, trade and consumption of each of the energy item described is the product of an aggregate volume and a mean price. Beyond these two principles, the method of data hybridisation is not standardised. A typology of the different procedures may be proposed by considering that the second accounting principle imposes that in the process of making consistent the three sources of data (volumes, prices and money flows), only two of this three variables can be regarded as independent of each other for any economic operation described. Then the various procedures are defined by(*i*) the choice of which statistics are kept unchanged from the raw data sources (‘fixed’ variables) and which variable is modified to meet the second accounting principle and (‘adjusted’ variables); (*ii*) the technical procedure pinpointing the adjustments made to the variables selected for adjustment.

To our knowledge, the bulk of efforts to build and document energy-economy hybrid databases for E3 model calibration has been carried out in the context of the Global Trade Analysis Project (GTAP). This led to different hybrid databases: GTAP 4E (Malcolm & Truong 1999), GTAP 5E (Burniaux & Truong 2002), GTAP 6E (Mcdougall & Lee 2006) and GTAP-EG (Rutherford & Paltsev 2000). One strength of GTAP databases is to provide harmonised national accounts for a large number of countries or regions and insure the consistency of bilateral trade flows. This feature imposes specific accounting constraints in the hybridization procedure compared to the single region case and should be taken into account when assessing the quality of the resulting hybrid I-O table at a given regional level.

With this in mind, we compare for the single region level existing hybridisation procedures with one another with the IMACLIM procedure we propose and detail below in **Table 2-1**.This table gives for each method the row data sources, the data that are not altered (fixed variables), and the data that are modified in the process (adjusted variables). GTAP-E databases cross the general GTAP accounts with IEA energy balances and various data on prices and taxes. The databases integrate the richness of the information available notably on the variety of user-specific energy purchasing prices at regional scale. Nevertheless the consistency of energy trade flows takes precedence in the hybridisation procedure to the detriment of regional I-O flows. As a result energy volumes, prices and I-O money flows are altered in the process in a possible large magnitude (Sands et al. 2005). This drawback is arguably quite detrimental for energy-policy analysis at the single region scale. The GTAP-EG procedure preserves IEA energy volumes and most of the prices and adjusts I-O values and energy value-added.

The two last hybridization procedures represent, to our knowledge, the existing documented hybridisation procedure for national analysis - the Second Generation Model (SGM) and the IMACLIM models – They thus do not have the additional constraint to balance international flows and are applied to the development of specific databases. The SGM procedure (Sands et al. 2005) conserves both the value-added of energy sectors and the volume of energy produced and consumed, and it adjusts an average production price for each energy good. This procedure keeps unaltered the total value of energy flows and the aggregate GDP, but it does not use the information about energy prices and ignores the heterogeneity of specific margins on prices across consumers. In addition, it uses the values of energy flows reported by national accounts, which, as we will see below may overestimate the energy bills paid by economic agents.

Hybrid database	Scope of analysis and data sources (values/quantities)	Fixed variables	Adjusted variables	Used by model
GTAP-E	Multi-country (GTAP / IEA*)	E volumes, traded E prices, traded	GDP E value added E volumes, domestic E prices, domestic	GEMINI-E3 (Bernard & Vielle 2007)
GTAP-EG	Multi-country (GTAP / IEA*)	E volumes, all E prices	GDP E value-added	GTAP-EG model
SGM	One country (national accounts / energy statistics)	E volumes, all E value-added Total GDP	E prices, all	SGM (Fawcett & Sands 2005)
IMACLIM	One country (national accounts / energy statistics)	E volumes, all E prices, all Total GDP	Non-E sectors value (*cf. infra*)	IMACLIM-S (Combet et al. 2010)

* International Energy Agency

Table 2-1 Four examples of hybridisation procedures

The hybridization method developed for the IMACLIM modelling framework follows three guiding rules. First, the correction of statistical gaps is carried out in such a way that both the total size of the economy (measured by GDP) and the data on energy quantities and prices coming from national energy statistics are preserved and fully used. Secondly, net-of-taxes purchasing price heterogeneities faced by the different economic agents (sectors and households) are introduced. This means that the value-added of energy production is deduced from energy statistics and not from national accounts data. Therefore, the description of the energy content of the national economic activities is preferably derived by aggregating information from specialised data sources at the aggregation level chosen in the model (production sectors and final consumers).

In what follows we illustrate the method on the 2010 French economy, considering 15 energy products and 12 energy-intensive productions (as described in appendix 6.2, p.23), *i.e.* disregarding possible extensions to other similarly homogeneous material flows (*e.g.* agricultural products or heavy industries). The method develops in three main steps (Figure 2-1):

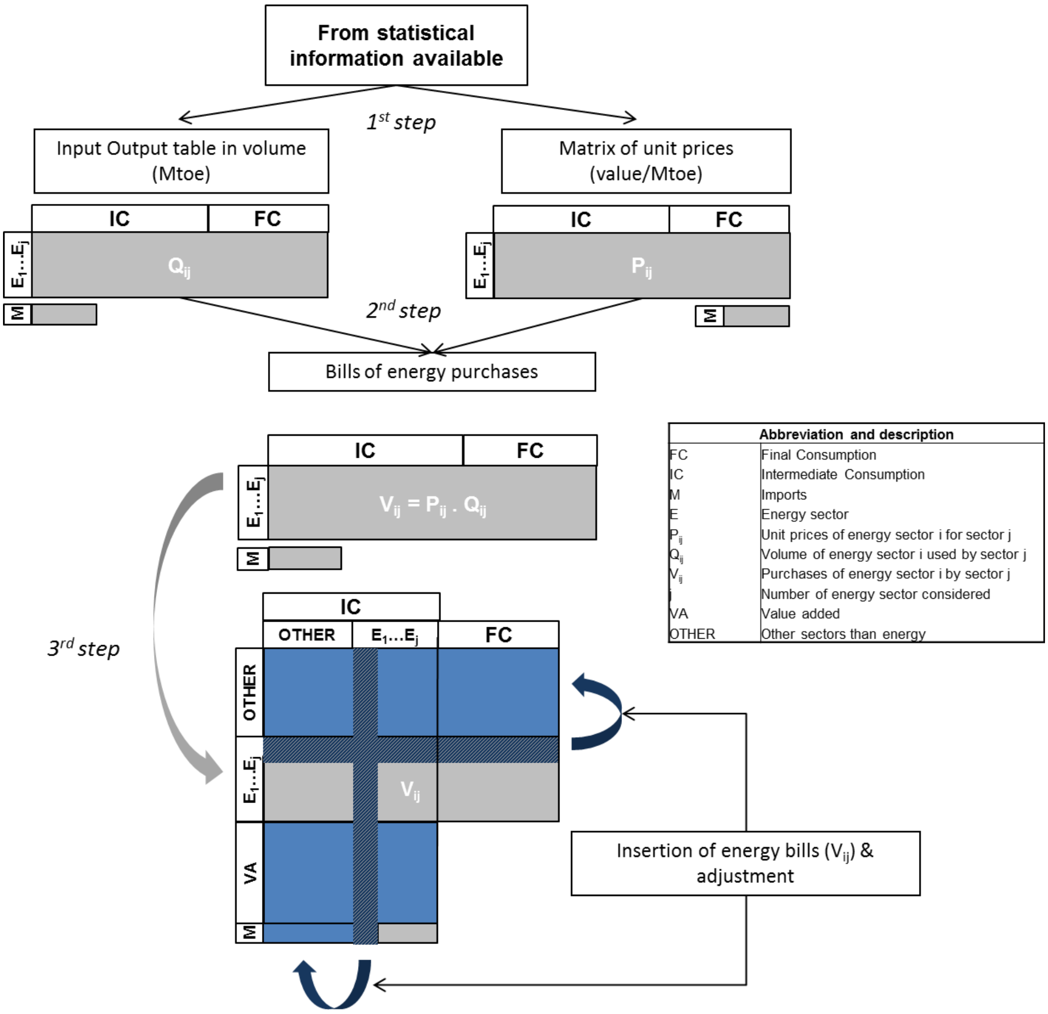

Figure 2-1 Overview of the IMACLIM hybridisation procedure

- The first step consists in reorganising the physical datasets, namely the energy balance (in million tons-of-oil equivalent, Mtoe) and energy prices (in Euros *per* Mtoe, €/Mtoe), into input-output formats compatible with that of national accounts (*cf.* Table 2-2 for the French data aggregated in two goods). As regards consumptions, this is not only a question of reallocating the physical energy flows of the energy balance to production sectors or households; rather, this entails re-interpreting the flows in national accounting terms, *i.e.* sorting out those that indeed correspond to an economic transaction between national accounting agents, or even combining some of them to compute such flows (*e.g.* assigning to accounting sectors the fuel consumptions of electricity autoproducers).

- The second step is the straightforward reconstitution of energy expenses at the same level of disaggregation by the term-by-term multiplication of the volume and price tables.
- The third step consists in plugging this matrix of energy expenditures into the system of national accounts and to adjust other components of the system to maintain the accounting identities, without modifying the total value-added of domestic production. This is done (*i*) for all producing sectors and households, by compensating the difference between the recomputed energy expenditures and the original statistics through an adjustment of the expenses on the most aggregated non-energy good—a composite remainder of not specifically described economic activities, usually encompassing all service activities in E3 models; (*ii*) for the energy sectors, by adjusting all non-energy expenses (including value-added) *pro rata* the adjustment induced on total energy expenses.

Hybrid values

2010 - Energy/quasi quantities (Mtoe)	COMPOSITE	ENERGY	C	G	I	X	**Total uses**
COMPOSITE	1 635	27	945	484	349	443	**3 884**
ENERGIE	87	89	60	-	-	33	**269**

Output	*3 437*	111
M	*455*	157
Total supply	**3 892**	**269**

2010 - Prices (€/toe for energy)	COMPOSITE	ENERGY	C	G	I	X
COMPOSITE	1 010	1 010	1 078	1 078	1 078	1 000
ENERGY	686	384	1 204			505
Distributed output	**1 000**	**761**				
M	**1 000**	**368**				

Table 2-2 Energy quantities and unit prices for hybridisation procedure

The full technical details of each step are given in appendix 6.1, p.16.

A complementary, paramount step is then motivated by observing, on the price data of 2010 France, a wide gap in the unit prices faced by firms and households. A closer scrutiny of price data, available both net-of-taxes and all-taxes included, confirms that this gap is not caused by taxation alone, but reflects contrasted pricing policies. It unquestionably translates extra actual costs incurred for the fragmented distribution to individual households, be they administrative or technical in nature. It is however doubtful that any data outside undisclosed corporate data could allow a meaningful distribution of these extra costs over the cost structure of energy production.

Because of this lack of information we introduce a set of 'specific margins' aggregating, for each economic agent category, the deviations of the basic price faced by each economic agent from the average basic price emerging from the cost structure. By construction these aggregate margins compensate, and the balance of each energy sector (or the energy aggregate in our numerical example here) is not modified (Table 2-3).

National accounts values

2010 - Million of euros	COMPOSITE	ENERGY	C	G	I	X	Total uses
COMPOSITE	1 563 850	40 288	1 010 980	521 643	376 721	444 564	**3 958 046**
ENERGY	80 001	88 622	80 350	-	-	15 589	**264 561**
Labour net	732 458	8 010					
Labour taxes	401 063	4 386					
Ouput taxes	55 339	1 967					
K	522 131	16 061					
M	448 519	64 145					
VAT	120 266	14 732					
Excise E IC	-	7 199					
Excise E FC	-	16 378					
Excise Oth.	35 067	1 546					
Total supply	**3 958 693**	**263 333**					

Hybrid values

2010 - Million of euros	COMPOSITE	ENERGY	C	G	I	X	Total uses
COMPOSITE	1 651 628	27 516	1 019 041	521 643	376 721	443 497	**4 040 047**
ENERGY	59 387	34 229	72 289	-	-	16 656	**182 561**
Labour net	734 346	6 122					
Labour taxes	402 097	3 352					
Ouput taxes	55 836	1 470					
K	526 016	12 176					
M	454 823	57 841					
SMC	-	9 279					
SME	-	-17 346					
SMFC	-	8 913					
SMG	-	-					
SMI	-	-					
SMX	-	-846					
VAT	120 847	14 732					
Excise E IC	-	7 199					
Excise E FC	-	16 378					
Excise Oth.	35 067	1 546					
Total supply	**4 040 047**	**182 561**					

Abbreviation	
C	Consumption
G	Government
I	Investment
X	Exports
K	Capital
M	Imports
SMC	Specific margins on composite
SME	Specific margins on energy
SMFC	Specific margins on final consumption
SMG	Specific margins on government
SMI	Specific margins on investment
SMX	Specific margins on export
VAT	Value added taxes
Excise E IC	Excise on energy interm. consumption
Excise E FC	Excise on energy final consumption
Excise Oth.	Other excise

Table 2-3 National accounts and hybrid IO table of France, 2010

As mentioned in section 1, the three sources of information (for values, prices and volumes) are not spontaneously consistent. A practical example is the gaps that can be observed between the values published by national accounts for energy uses including exports (264 billion Euros) and the values that can be computed using energy sector data on volumes and prices (182 billion Euros). In this case, we obtain a difference of 31% (Table 2-4). These figures reduce the weight of energy in the French economy by 2 percentage points, from 6% to 4%.

Beyond the unavoidable non measurable statistical gaps linked to data collection and process by different organisations, one manageable source of discrepancy between the figures stems from differences of nomenclature related to energy flows in the different statistical systems. Another source of discrepancy is energy trading, which developed in France in the wake of market liberalisations. In the national accounts sector of electricity and gas distribution, trading amounts to 45 billion Euros, a significant share of the observed 80 billion Euro discrepancy. The sector as seen by national accounts is thus much larger than direct energy consumption built by hybridisation procedure. For all energy policy purposes other than those focused on energy markets organisation, indistinctly treating this trading as any physical consumption cannot but flaw analysis.

2010 France	From National accounts[a]	Hybrid table[b]	Gap
Total energy uses (inc. exports), million Euros	264 561	182 561	31%
Share of energy uses in total uses	6%	4%	31%
Share of firms in energy expenses (exc. exports)	68%	56%	12 pts
Share of households in energy expenses (exc. exports)	32%	44%	-12 pts

[a] Source: INSEE (*Institut National de la Statistique et des Études Économiques*)
[b] Source: combination of IEA, INSEE and ENERDATA data

Table 2-4 Differences between national accounts and hybrid table (in value)

The hybridisation procedure also induces changes on major determinants of policy analysis. First, it alters the share of firms and households in total energy expenses. In the case of France the weight of households in energy expenses is higher in the hybrid IO table than it is in national accounts; the share of firms is conversely lower.

Secondly, using an IO table from national accounts to calibrate any model involves disaggregating all expenses in prices and quantities. This is standardly done by assuming basic prices that are normalized and undifferentiated across economic agents. Setting the basic prices of the energy and composite good at 1000 Euros we obtain relative prices and quantities markedly different from those reflecting actual markets and directly feeding in our hybridisation method (Table 2-5).

Non-hybrid values

2010 - Energy/quasi quantities (Mtoe)	COMPOSITE	ENERGY	C	G	I	X	**Total uses**
COMPOSITE	1 548	40	938	484	349	445	**3 803**
ENERGIE	71	79	58	-	-	16	**223**

Output	*3 355*	159
M	*449*	64
Total supply	**3 803**	**223**

2010 - Prices (€/toe for energy)	COMPOSITE	ENERGY	C	G	I	X
COMPOSITE	1 010	1 010	1 078	1 078	1 078	1 000
ENERGY	1 124	1 124	1 389	1 389	1 389	1 000
Distributed output	**1 000**	**1 000**				
M	**1 000**	**1 000**				

Table 2-5 Energy quantities and unit prices from national accounts

The unit prices used to build the hybrid IO table appear to be much more differentiated between agents that the implicit unit prices of national accounts (Table 2-6). The energy purchasing price for households is higher than the price for firms in both datasets, but the difference reaches 56% in hybrid IO table when it is only of 19% (explained by tax differences) according to national accounts, assuming a unique basic price across agents.

2010 France	From National accounts	Hybrid table[a]	Gap
Share of firms in energy consumption (exc. exports)	72%	75%	-3%
Share of households in energy consumption (exc. exports)	28%	25%	9%
Differences between energy purchasing prices for households/firms	19%	56%	-

[a] Source: combination of IEA, INSEE and ENERDATA data

Table 2-6 Differences between non hybrid and hybrid IO for quantities and prices tables

All these figures may change energy policy implications. Indeed, as amount of firms' energy consumption is overvalued in non-hybrid table, any reduction in their consumption may be overestimated when calibration of CGE model is done on national accounts. Conversely, the impact of energy policy, like a reduction in consumption, for households may be underestimated.

Our hybridisation procedure is an original method with its limits. First, the adequacy of the method hangs on the quality and disaggregation of price data. Notwithstanding, we advocate working on explicit, improvable price x quantity disaggregations rather than keeping on using non-disambiguated national accounting aggregates. Secondly, the method is highly data- and time-intensive, even for countries with a developed statistical corpus as France. It is therefore by essence a national method, or a method applicable to integrated regional ensembles for which aggregate statistics, especially price statistics, are available.

3 Impact on policy analysis

In this last section we illustrate the consequences of basing policy analysis on hybrid accounts with agent-differentiated prices rather than on unmodified national accounts and the standard single-price assumption. To do so, we calibrate a standard computable general equilibrium (CGE) model on 2010 France and explore the welfare costs of energy consumption cuts induced by an excise tax on energy consumptions. For the sake of concision, we postpone the full set of equations of our model to appendix 3 (p.25) below, while the following subsection only synthesises its main features.

3.1 Model overview

Our illustrative, standard CGE model is of a 'KLEM' nature that matches the level of aggregation of the input-output data reported above: it disaggregates two primary factors of production, capital (*K)* and labour (*L)* and, considering the focus of our study, two goods only, one energy aggregate (*E*) and one remainder of economic activity, or composite good (*M* for materials in the 'KLEM' acronym, although we will retain this letter to designate imports).

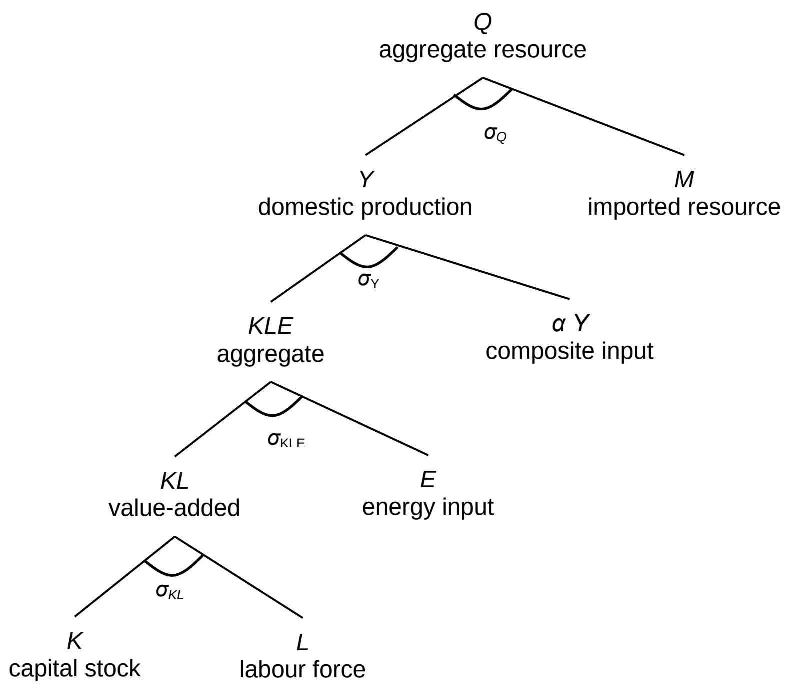

Figure 3-1 Nested production structure of a 'KLEM' model

Production of both goods is represented as a nested structure of primary and secondary factor consumptions that combine following Constant Elasticity of Substitution (CES) functions (Figure 3-1). At the bottom of the structure, acknowledging recommendations of Van Der Werf (2008) and Okagawa & Ban (2008)[1], capital *K* and labour *L* trade off to produce a value-added (*KL*) aggregate, which then trades off with energy *E* to produce a *KLE* aggregate. This in turn is combined with non-energy secondary inputs to produce domestic output *Y*. Beyond domestic production, *Y* itself aggregates with imports *M* to constitute total resource *Q*. The four elasticities characterising these trade-offs for each of the two represented sectors are (painstakingly) drawn from the literature (Table 3-1).

Final demand of the two goods is disaggregated in three uses: household consumption (*C*), consumption of public administrations (*G)* and investment (*I)*. Households devote a constant share r_C of their income *R*, the sum of primary factors payments and social transfers, to consumption. They trade off energy to composite consumption to maximise their welfare, which is a CES function of both consumptions. The elasticity of this trade-off is calibrated to accommodate a .6579 own-price elasticity of their energy consumptions, as inferred by weighting the GTAP model elasticities for housing utilities and transport and communications (Hertel et al. 2008) with the budget shares of domestic and private transportation energy consumptions in total household energy expenses.

Public consumption *G* and aggregate investment *I* regard the composite good only. The former is specified as a constant share of GDP, the latter as a constant share of income. The maintained pre-existing tax rates, together with the explored excise taxes on energy consumptions (*cf. infra*), provide public income. Social transfers to households balance the public budget.

[1] Both authors demonstrate the higher relevance of the retained '*KL-E*' structure compared to other possible nested combinations of the *K*, *L* and *E* factors.

Elasticity	Name (*cf.* appendix 6.3)	Value, composite production	Value, energy production
Substitution of capital K to labour L	σ_{KL}	0.4200[a]	0.4501[d]
Substitution of value-added *KL* to energy *E*	σ_{KLE}	0.3518[a]	0.2374[d]
Substitution of *KLE* aggregate to non-energy 2[ndary] inputs α Y	σ_Y	0.6678[b]	0.2378[d]
Substitution of domestic variety Y to imported variety M	σ_Q	2.0000[c]	3.7610[d]

[a] The elasticity computed by van der Werf (2008) for the aggregate French economy on time-series analysis.
[b] The average of the elasticities computed by Okagawa (2009) for several activity sectors weighted by the contributions of these sectors to non-energy output of France 2010.
[c] Inspired by the Armington elasticities of the non-energy sectors of the GTAP model (Hertel *et al.*, 2008).
[d] The average of the corresponding elasticities of the GTAP model for 6 energy goods weighted by the contribution of these goods to the sum of domestic production and imports of energy goods in 2010 France 2010.
[d] The average of the elasticities computed by Okagawa (2009) for the Mining and Electricity, gas and water sectors weighted by the contribution of such sectors in their KL, KLE and KLEM aggregates.

Table 3-1 Substitution elasticities of a 'KLEM' model of France

We must immediately stress that we only resort to such a simple 'KLEM' abstraction to set our analysis in a common-knowledge, fully controlled modelling background. Indeed, we recommend regarding with great caution the absolute results of such a model. We have elsewhere criticised the inadequacy of CES functions to faithfully represent the inertias inherent to the complex engineering systems embodied in energy production and consumption (Ghersi & Hourcade 2006). What is more, to implement such functions we have to resort to ill-adapted elasticity estimates, of various sources of uncertain compatibility, and crudely adjust them (*cf.* note to Table 3-1). We also apply them to the modelling of energy consumption constraints probably far beyond the range of their validity—fundamentally limited to the immediate vicinity of the price and quantity fluctuations observed in the time-series or cross-sectional data from which they were estimated. The reader should bear in mind, though, that this is indeed what many modelling studies do when they estimate drastic carbon policies as Factor 4 or Factor 5 (75% or 80% cuts of greenhouse gas emissions) objectives. Also, our purpose is indeed to illustrate the impact of two opposed benchmarking practices by comparing their policy analysis consequences, not on the policy analyses themselves.

3.2 Model implementation and results

We implement the 'KLEM' model of section 3.1 with alternative calibration on hybrid *vs.* unmodified French accounts to compute the welfare costs of inducing energy consumption cuts through excise taxes. We first explore a full range of cuts, by 5%-steps up to a 95% reduction, then by 1%-steps up to a 99% reduction—noting that, by nature, CES functions forbid modelling 100% cuts. With a view to discriminate the sources of discrepancy we alternatively target firms' consumptions and households' consumptions, while also reporting on total energy consumptions for the sake of reference. In the two former cases we limit the excise tax increase to the targeted consumption. As stated in section 3.1, the generated tax proceeds accrue to the public budget, which is in turn balanced by transfers to households once public expenditures have been financed.

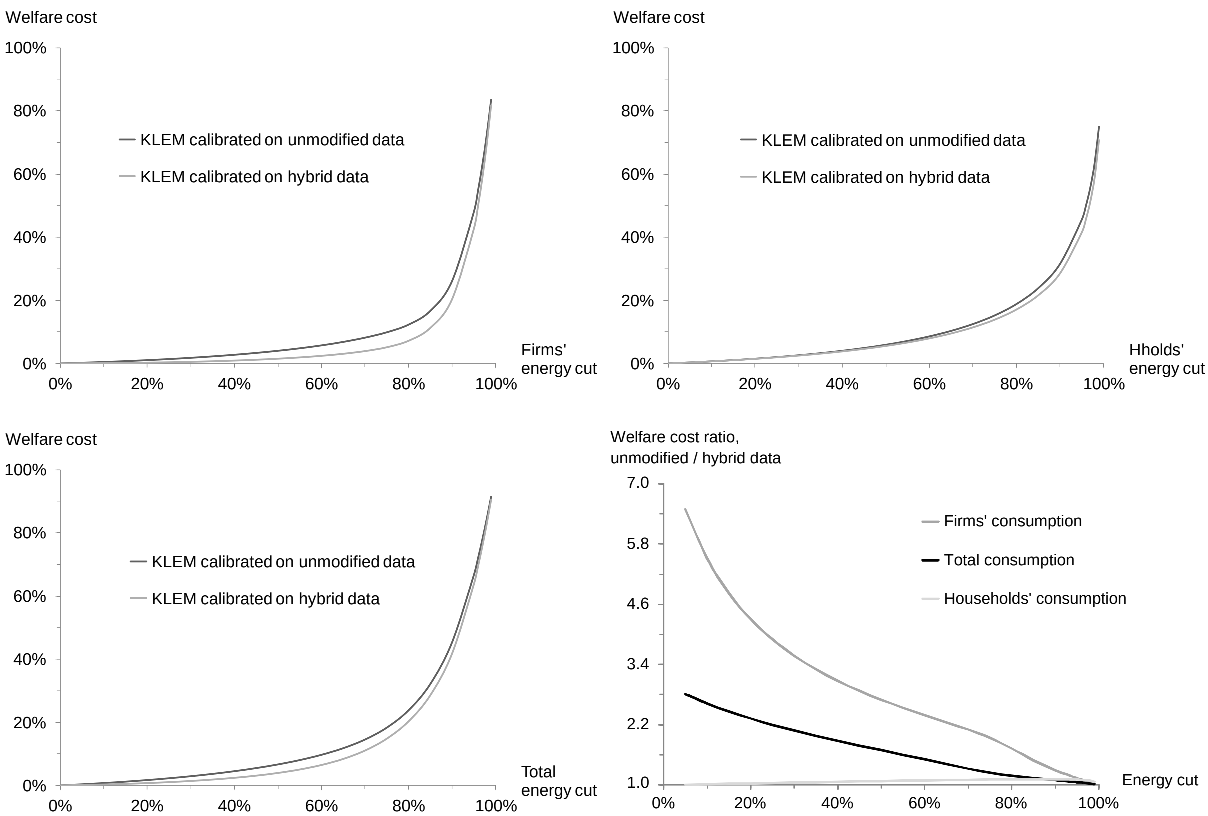

Figure 3-2 Welfare costs of price-induced energy cuts based on unmodified *vs.* hybrid data

We use the marginal cost curves of energy cuts as a synthetic measure of modelling results, reporting on each of our three targets: firms', households' and total energy consumptions (upper left, upper right and lower left panel of Figure 3-2). At first sight, (*i*) hybridised data produce systematically lower welfare costs estimates, for both targets (and of course their combination in one aggregate target) and for the whole range of possible energy quotas; (*ii*) the divergence in welfare cost estimates is stronger for firms than it is for households (and the gap when targeting total consumption is understandably of intermediate size). These results simply echo (*i*) the direction and (*ii*) the relative sizes of the corrections of the energy expenses of both agents (Table 2-4, p.**Erreur ! Signet non défini.**): hybridisation decreases the energy expenses of both agents; it cuts by close to half the 168 billion Euros energy expenses of firms, to 94 billion Euros, while it only adjusts those of households by 10%, from 80 to 72 billion Euros. This straightforward interpretation derives from the well-known property of our standard, CES-dominated modelling framework that expenses only matter, and underlying volumes do not.

A third observation is that the divergence of cost estimates seems to follow comparable profiles for both targets. Indeed, it vanishes as the targeted cuts approach 100%, for the simple reason that the induced welfare costs converge to 100% as well—another artefact of our generalised CES assumption.

For the smaller cuts, however, discrepancies arise: in the case of households, the comparatively much smaller divergence over the whole range, as we already noticed—the cost ratio never exceeds 1.11, vanishes for the smaller cuts as well as when approaching the 100% limit. It is interesting to note that the maximum cost divergence, at 10%, closely matches the correction of households' expenses. This is yet another direct consequence of our use of CES functions, in this instance for representing households' utility.

Targeting firms' consumptions has much more contrasted repercussions. The deceptively small absolute magnitude of the estimation gap for the lower consumption cuts hides ever-increasing relative gaps as the target's ambition decreases. , as testified by the ratio of both assessments (Figure 3-2, lower right panel). For a 5% cut of firms' consumptions the welfare cost estimated on unmodified data, although a small 0.21%, is over 6 times (6.48 times) that estimated on hybridised data; up to a 70% cut it is consistently more than twice its counterpart on hybridised data. In the case of firms the impact on cost assessment thus greatly magnifies the extent of the expense correction, of 44%. This must be the combined consequence of a more complex behaviour, which includes feedback loops to the energy consumptions of input productions through the input-output matrix, and to the broader macroeconomic framework extending to the primary factors markets and international trade. We reserve to further research a possible analytical disambiguation of these mechanisms.

4 Conclusion

A first objective of this paper was to underline the fact that building a hybrid social accounting matrix has a non-marginal impact on the empirical description of the initial state, and therefore, on the policy evaluations drawn from hybrid CGE models. The hybridisation procedures used to reconcile energy data on price and quantities with input-output tables coming from national accounts has a direct impact on the description of empirical features that always matter for energy policy evaluation: the economic size of energy flows, the relative share of energy bills paid by productive sectors and final demand, the relative energy prices paid by each economic entities.

This methodological problem is general as the statistical gaps among those sources are not only due to sample bias, but to differences in the content of statistical aggregates that describe energy items in both sources. The solution proposed in this paper can be extended to the description of other material flows than energy - like surfaces (m^2) or distances (passenger-km, ton-km) - or to other countries or years, and it can allow the development of new generations of hybrid CGE models useful for sustainable development analysis. Compared with the other hybridisation techniques, our solution replaces the nomenclature of material flows in the input-output matrix by the nomenclature used in material balances and statistics. This allows for keeping unchanged the whole size of the economy, as recorded in national accounts, while including without alteration the quantitative information about material flows, prices and quantities that come from specialised statistics. The "validity" of the description will therefore be based on the accuracy of those statistics and their aggregation. The real contribution of the technique - besides giving a basis for the dialogue between macroeconomic and technical analyses - is to give a measure of empirical uncertainties in available data. The CGE model may then be used to analyse the sensitivity of the results to those uncertainties.

A second objective of this paper was to show that this impact of the hybridisation techniques on the empirical description of the initial state exists with all types of CGE models, even with a small and highly aggregated "standard" neoclassical model like the one used in this paper. The magnitudes of the impacts will nevertheless vary with the modelling assumptions about technical change and the macro functioning of the economy, as well as with the levels of aggregation of productive sectors and economic agents, and with the specific data at hand (year, country, and sources). In particular, the differences between the policy evaluations drawn from hybrid CGE models and "standard" neoclassical CGE models are of course magnified by the use of bottom-up models and engineering expertise in place of aggregate production functions calibrated on econometric estimations. But this impact of the modelling and aggregation choices has already begun to be discussed elsewhere, but has not been isolated from the impact of hybridisation techniques on the initial empirical description.

The primary motivation for elaborating hybrid social accounting matrices remains of course to embark in CGE frameworks the experts' information about future technical change and energy saving possibilities at different time horizons. Therefore, it will be a natural follow up to this paper to compare the impact on evaluation of the different techniques and assumptions used to realise this dialogue between bottom-up engineering expertise and top-down macroeconomic modelling.

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6 Appendixes

6.1 Technical details of the IMACLIM hybridisation procedure illustrated on the example of France for 2010

6.1.1 Step 1: Elaborating supply-use tables in physical units

Because tables of resources and uses of physical flows and prices are not available from statistical institutes in a standardised manner, it is compulsory to build them through the collection of different data sources. The accuracy and robustness of this process obviously depends on the context considered.

Starting from IEA energy balance aggregated in three energy types[2] for the sake of simplicity (Table 6-1), we can identify domestic production (R1), international trade (R3-4), transformation processes and the distribution of final consumption across activities (R10-24).

	2010 - Million ton oil-equivalent, Mtoe	**Primary energy**	**Final energy**	**Non-valuables energies**	**Total**
R1	Production	1	121	13	*135*
R2	Imports	68	94	0	*162*
R3	Exports	-0	-33	0	*-33*
R4	Marine & Aviation bunkers	0	0	0	*0*
R5	**Total Primary Energy Supply**	**69**	**182**	**13**	***265***
R6	Transformations	-69	-17	-0	*-86*
R7	Energy industry own use	0	-10	0	*-10*
R8	Losses	0	-4	0	*-4*
R9	**Total Final Consumption**	**0**	**151**	**13**	***164***
R10	Iron and steel	0	4	0	*4*
R11	Non ferrous metals	0	1	0	*1*
R12	Non metallic minerals	0	4	0	*4*
R13	Construction	0	1	0	*1*
R14	Chemical and petrochemical	0	6	0	*6*
R15	Paper, pulp and print	0	2	1	*2*
R16	Mining and quarrying	0	0	0	*0*
R17	Transport equipement	0	1	0	*1*
R18	Other industries	0	9	1	*11*
R19	Transport	0	48	0	*48*
R20	Residential	0	36	8	*45*
R21	Agricuture and forestry	0	4	0	*4*
R22	Fishing	0	0	0	*0*
R23	Other sectors	0	27	3	*30*
R24	Non-energy uses	0	8	0	*8*

Source : IEA, 2010

Table 6-1 : Simplified structure of the IEA energy balance

Difficulties of the transformation from the energy balance in Table 6-1 to a supply-use format are twofold. On the one hand, the energy balance does not distinguish between intermediate consumption of productive sectors and households' final demand because it does not include information whether energy consumption serves to produce goods or is directly burned to create energy services (for mobility, heating...). This question arises essentially for transport (R19) and residential (which mix residential and tertiary- R20), and the neat decomposition for these two activities is dependent upon the availability of complementary datasets (e.g., transport and

[2] The methodology explained, as follow, has been done for : Crude oil/ LNG/feedstocks, Natural gas, Coking coal, Bituminous coal, Coke oven coke, Other coal products, Gasoline, LPG, Jet Fuel, Diesel and heating oil, Heavy fuel oil, Other petroleum products, Biomass & Waste, Biofuels, Electricity, Nuclear, Hydro, Wind/Solar PV/Tide, Heat/Geothermal/Solar Th.

households' surveys). On the other hand, energy flows must be explicitly reconstituted to exclude the elements of the balance that do not correspond to commercial energy uses (e.g., non-energy uses or renewable energies).

In practice, the elaboration of physical accounting systems can be divided in three sub-steps:

Sub-step 1.1: disaggregating the description of certain products or uses. This step requires additional information from external statistical sources to define the split of quantities reported in an aggregate manner in the balance (in the absence of information, ad-hoc assumptions must be made). In the case of France, an important feature is, for example, to distinguish fuels used for transport from those used in buildings and the share of these consumptions that can be attributed to households and sectors respectively. To this aim, the description of refined products in the energy balance must be complemented by more precise information on the details of uses.

Table 6-2 illustrates the disaggregation of transport sector using external sources of information.

	2010 - Million ton oil-equivalent, Mtoe	**Primary energy**	**Final energy**	**Non-valuables energies**	**Total**
R1	Production	1	121	13	*135*
R2	Imports	68	94	0	*162*
R3	Exports	-0	-33	0	*-33*
R4	Marine & Aviation bunkers	0	0	0	*0*
R5	**Total Primary Energy Supply**	**69**	**182**	**13**	***265***
R6	Transformations	-69	-17	-0	*-86*
R7	Energy industry own use	0	-10	0	*-10*
R8	Losses	0	-4	0	*-4*
R9	**Total Final Consumption**	**0**	**151**	**13**	***164***
R10	Iron and steel	0	4	0	*4*
R11	Non ferrous metals	0	1	0	*1*
R12	Non metallic minerals	0	4	0	*4*
R13	Construction	0	1	0	*1*
R14	Chemical and petrochemical	0	6	0	*6*
R15	Paper, pulp and print	0	2	1	*2*
R16	Mining and quarrying	0	0	0	*0*
R17	Transport equipement	0	1	0	*1*
R18	Other industries	0	9	1	*11*
R19	**Transport - Households**	0	24	0	*24*
R20	**Transport - Sectors**	0	24	0	*24*
R21	Residential	0	36	8	*45*
R22	Agricuture and forestry	0	4	0	*4*
R23	Fishing	0	0	0	*0*
R24	Other sectors	0	27	3	*30*
R25	Non-energy uses	1	12	0	*13*

Source : IEA; Odyssee Enerdata - 2010

Table 6-2 : Energy balance after sub-steps 1.1

Sub-step 1.2: delineating the domain of analysis. In practice, this comes down to isolating the crucial components of the balances for the question under consideration. This means suppressing the rows and columns that correspond to activities outside the core analysis without introducing disequilibria in the balance. For example, in the case of France, the withdrawal of renewables and wastes is not problematic because it is a rather independent production process and it is then sufficient to add the volume of electricity produced from these sources. On the contrary, suppressing non-energy uses requires a parallel decrease of resource.

Sub-step 1.3: aggregating and allocating quantities of the energy balance in Table 6-2 according to the nomenclature of the final input-output matrix. This imposes to adopt a level of aggregation compatible with the nomenclature of national accounts, which comes down to aggregating columns and rows consistently with the level of description adopted in the input-output matrix. In our illustrative example, the columns have not to be modified because they directly correspond to the level of disaggregation of energy in national accounts; but, concerning rows, the study being focused on households, intermediate consumption by tertiary activities must not be isolated and can then be aggregated with the consumption by other sectors.

These last two sub-steps cannot be completely automated because they involve number of tradeoffs depending on available datasets, the context and the question under consideration. The most important choices concern:

i. ***How to assign final energy use.*** When surveys on consumption per use are missing (e.g., "heavy fuel consumption and domestic residential sector and tertiary use" CEREN), it becomes necessary to use information from 'close' enough other economies where these data exist or to deduct the diffracting coefficients from national accounts by adapting the Leontief technique(Moll et al. 2007).
ii. ***How to establish input-output description consistent with the level of aggregation.*** Volumes of energy must be allocated in accordance with the concepts of supply and use tables (Resources, Uses and Intermediate Consumption). The way to do this assignment depends on the level of aggregation used. In the example of France, only cross-sectoral exchanges associated with refining are described (disaggregated industry), other processing methods are not detailed (aggregated sector.
iii. ***How to assign own uses.*** Most of the time, the amount of own used energy is not linked to any economic transaction, but must be recognized because they account for the estimation of technical coefficients, CO_2 emissions, and the opportunity cost they represent during the introduction of the carbon price (because losses and own uses reduce the net efficiency of the transformation). In particular, it seems consistent to identify own uses with distribution losses for coal, gas and electricity, and to transformation processes for refineries.
iv. ***How to describe the processes of co-productions.*** The relationship between coproductions is not described in the symmetrical input-output tables, which conventionally postulates a separation of the conditions of goods' production. This assumption is not acceptable in any case (for example, in studies of agricultural production systems) and flows of co-production must then be described as well as the technical fundamentals which link the productions. In the example of France, this question remains of second order: in the circuit of commercial energies, only a small amount of "returns" of refined products and industrial gases come from other production processes (petrochemicals and inorganic chemistry) and we treat them as domestic resources into refined products and gas.

Finally, we are able to get the balance a matrix in physical unit, in Table 6-3 but for more simplicity for next steps, sectors have been aggregated into one composite sector.

2010 - Million ton oil-equivalent, Mtoe	Intermediate consumption			Final consumption			*Total uses*	Production	Import
	Composite	Primary energy	Final energy	Final demand	GFCF*	Export			
Primary energy	0	0	70	0	0	0	*70*	2	68
Final energy	87	0	19	60	0	33	*198*	109	89

Table 6-3 : Energy Input-output table

6.1.2 Step 2: Elaborating balances of energy bills

This second step is very simple in its principle: it consists in multiplying on a one-to-one basis the input-output tables in quantities and prices to obtain a table in monetary units which corresponds to energy bills at the desired level of aggregation Table 6-4. This table is fully consistent with the energy statistics on the diversity of rates, energy consumption, carbon content, etc.

2010 - Million of euros	**Intermediate consumption**			**Final consumption**			***Total uses***
	Composite	**Primary energy**	**Final energy**	**Final demand**	**GFCF***	**Export**	
Primary energy	0	0	29 986	0	0	44	*30 030*
Final energy	59 387	32	4 212	72 289	0	16 612	*152 531*
Imports		29 535	28 306				

* Gross fixed capital formation

Table 6-4 : Balance of energy bills

6.1.3 Step 3: Aligning monetary and physical matrixes

Once the input-output tables that describe the economic circuit of energy flows in quantity, value and price have been built, it remains to integrate them into the national accounts input-output tables without changing the variables important for the empirical analysis. This is the hybridisation step as such (Figure 6-1) that can be analyzed in two stages: a work on the rows of the matrix currency (1 - Adjustment of uses) to insert the monetary matrix derived from step 2, and informing the energy bills paid; and a work on the columns (2 - adjustment of resources) which provides a description of the contents of these bills: the cost structure of one liter of fuel purchased, a kwh, etc. These columns describe the fixed and variable costs of industries that supply, process and distribute energy to consumers.

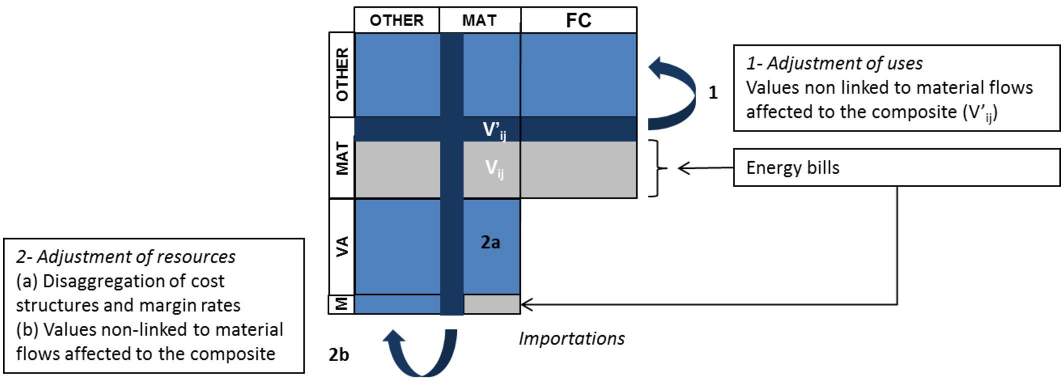

Figure 6-1 : Principles of alignment of material balances and monetary flows

The result is a modified input-output table in which the value added of energy flows is isolated from those corresponding to non-energy products from "energy branches" aggregated in the composite sector. This rearrangement in the nomenclature maintains the total value added of the economy, while specifying the description of energy circulation.

To illustrate the hybridisation process, we consider the case of France and start from input-output tables obtained from National Accounts (Table 6-5).

Millions of euros	Intermediate consumption			Final consumption			Total uses
	Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
Composite	1 576 798	263	27 077	1 532 623	376 721	444 564	**3 958 046**
Primary energy	1 698	0	39 270	-	-	1 255	**42 224**
Final energy	78 302	11	49 340	80 350	-	14 334	**222 338**
Value added	1 710 991	264	30 160				**4 222 607**
Total production	***3 367 789***	***538***	***145 847***				
Imports	448 519	41 539	22 606				
Taxes	141 738	147	53 885				
Total resources	**3 958 046**	**42 224**	**222 338**	**4 222 607**			

Table 6-5 : Input-Output tables in National Accounts

Sub-step 3.1**: **adjustments of uses. Starting from input-output in national accounts (Table 6-5), we replace the values of energy branches (R2, R3 in orange) by the values of reconstructed energy bills from Table 6-4. Differences are added to uses and imports of composite (all R1 and R6-C1, in dark blue). These operations do not affect the total value of uses, but change those of different products. Therefore, the supply-use balances are broken.

	Millions of euros	Intermediate consumption			Final consumption			Total uses
		Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
R1	**Composite**	1 667 967	727	10 450	1 540 684	376 721	443 497	**4 040 047**
R2	**Primary energy**	-	-	29 986	-	-	44	**30 030**
R3	**Final energy**	59 387	32	4 212	72 289	-	16 612	**152 531**
R4	**Value added**	1 710 991	264	30 160				**4 222 607**
R5	***Total production***	***3 438 345***	***1 022***	***74 807***				
R6	**Imports**	454 823	29 535	28 306				
R7	**Taxes**	141 738	147	53 885				
R8	**Total resources**	**4 034 906**	**30 704**	**156 998**	**4 222 607**			
	Resources - Uses	**-5 141**	**674**	**4 467**				
		C1	*C2*	*C3*	*C4*	*C5*	*C6*	

In this example, the intermediate consumption of the composite good for the production of energy (first row, second or third column: L1-C3(2)) is estimated in order to keep the input ratio Composite/Energy for energy products given by the IOTnational accounts (R1-C3(2) / [R2-C3(2) + R3-C3(2)]). The balance of inputs is assigned to the composite consumption good for the production of composite (R1-C1).

Table 6-6 : Input-Output table after adjustments of uses

Sub-step 3.2: adjustment of resources. Balances between uses and resources are restored by manipulating the cost structure of industries (columns of the IOT). Values of imports and intermediate consumption are given by the energy statistics and other cost components - value added, margins, taxes on products - are adjusted to restore equality of resources with uses (

	Millions of euros	Intermediate consumption			Final consumption			Total uses
		Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
R1	Composite	1 667 967	727	10 450	1 540 684	376 721	443 497	**4 040 047**
R2	Primary energy	-	-	29 986	-	-	44	**30 030**
R3	Final energy	59 387	32	4 212	72 289	-	16 612	**152 531**
R4	Value added	1 716 132	-410	25 693				**4 222 607**
R5	***Total production***	***3 443 486***	***348***	***70 340***				
R6	Imports	454 823	29 535	28 306				
R7	Taxes	141 738	147	53 885				
R8	**Total resources**	**4 040 047**	**30 030**	**152 531**	**4 222 607**			
	Resources - Uses	**0**	**0**	**0**				
		C1	*C2*	*C3*	*C4*	*C5*	*C6*	

Table 6-7). Since, in our example, energy taxation is known (R7-C1/C2), the adjustment is made at the final value (line 3). Finally, in the case of France, the margin rate is modulated according to buyers, which helps to distinguish the purchase prices of the same product energy. After this last step, all accounting identities of the hybrid description are satisfied.

	Millions of euros	Intermediate consumption			Final consumption			Total uses
		Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
R1	Composite	1 667 967	727	10 450	1 540 684	376 721	443 497	**4 040 047**
R2	Primary energy	-	-	29 986	-	-	44	**30 030**
R3	Final energy	59 387	32	4 212	72 289	-	16 612	**152 531**
R4	Value added	1 716 132	-410	25 693				**4 222 607**
R5	***Total production***	***3 443 486***	***348***	***70 340***				
R6	Imports	454 823	29 535	28 306				
R7	Taxes	141 738	147	53 885				
R8	**Total resources**	**4 040 047**	**30 030**	**152 531**	**4 222 607**			
	Resources - Uses	**0**	**0**	**0**				
		C1	*C2*	*C3*	*C4*	*C5*	*C6*	

Table 6-7 : Input-Output table after adjustments of resources

It is useful to keep in mind some principles to guide the choice of adjusting resources. We can offer a procedure to select the set of assumptions to be used to isolate the cost structures of two products (Figure 6-2) with the objective of mobilizing the maximum available statistical information on intermediate consumption and unit costs of each input, labor, consumption of fixed capital and operating margin.

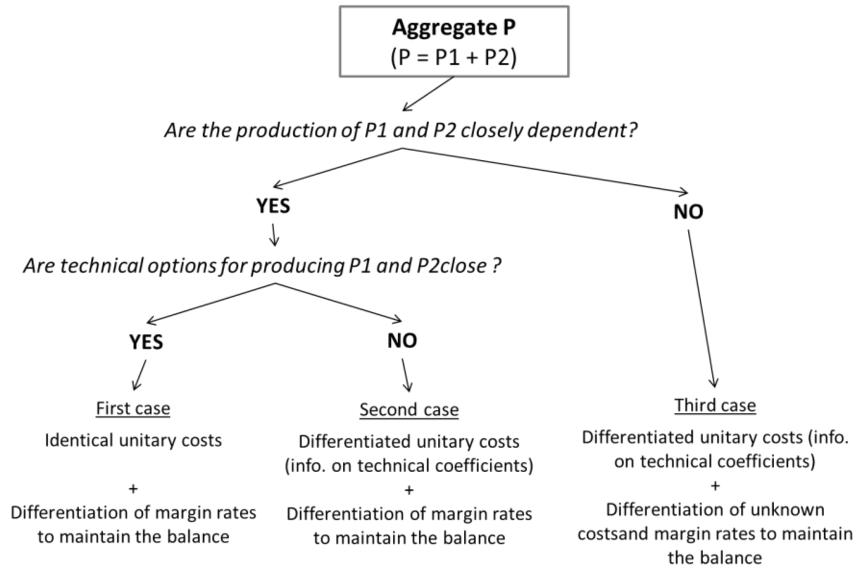

Figure 6-2 : Methodology for disaggregating cost structures and margin rates

We can then guide the search for information by discussing the conditions of production:

- ***First case***: productions P1 and P2 are the result of separate units, the level of dependence is low. It is then likely that the information on one or the other of the structures of this cost is available. This is the case of industries specialized and concentrated, like the nuclear industry that can be isolated from other energy industries.
- ***Second case***: P1 and P2 are products within the same units but with different processes. Information on technical coefficients (the unit quantities of inputs, capital, and labor) can be used to distinguish costs. This is the case, for example, for refined petroleum products which are derived from a combination of different methods of physico-chemical separation implemented in refineries.
- ***Third case***: the production unit and the processes are similar. Therefore, it is justified to retain the assumption of the same cost structure. Information is used either on unit costs or on the technical coefficients, but for both productions. Associated with the assumption of returns to scale and / or factor prices, this information can help reconstructing a structure of unitary costs for aggregates (since the total quantities produced are known). This case corresponds, for example, to the distinction between diesel and heating oil, used for transportation or heating (but these products are actually physically identical.

6.2 Appendix 2: Hybrid input-output table for France

France, 2010	Million of euros	Crude oil	Natural gas	Coking coal	Bituminous coal	Coke oven coke	Other coal products	Gasoline + biogasoline	LPG	Jet Fuel	Diesel and biofuel	Heating fuel	Heavy fuel oil	Other petroleum products	Electricity	Heat, Geothermal, Solar Th	Iron and steel	Non ferrous metals	Non metallic minerals	Construction	Chemical and petrochemical	Paper, pulp and print	Mining and quarrying	Transport equipement	Transport - Sectors	Agricuture and forestry	Fishing	Agri-food industry	Composite	Public consumption	Households consumption	Investment	Export	TOTAL USES
Energy sectors	Crude oil	-	-	-	-	-	-	7 408	773	2 360	10 897	4 149	2 025	1 609	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	29 246
	Natural gas	3	-	-	-	0	0	70	7	22	103	39	19	15	1 379	826	262	71	504	19	264	287	24	188	36	100	0	967	4 313	10 436	-	-	513	20 470
	Coking coal	-	-	-	-	602	163	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	784
	Bituminous coal	-	-	-	-	-	-	-	-	-	-	-	-	-	642	2	273	0	70	-	54	5	-	-	-	-	-	45	24	70	-	-	2	1 187
	Coke oven coke	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1 042	-	27	-	6	-	-	2	-	-	-	8	12	-	-	-	32	1 129
	Other coal products	-	-	-	-	81	22	-	-	-	-	-	-	-	148	-	113	-	-	-	-	-	-	-	-	-	-	-	2	58	-	-	1	426
	Gasoline + biogasoline	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	6	3	73	2	2	5	337	33	2	12	364	13 380	-	-	4 419	18 642
	LPG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	10	28	-	873	16	15	17	7	308	-	98	712	1 945	-	-	513	4 551
	Jet Fuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1 716	-	-	-	1	-	-	-	2 704	4 421
	Diesel and biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	28	139	62	1 581	46	50	104	8 445	1 644	161	260	7 861	21 211	-	-	1 408	43 026
	Heating fuel	-	-	-	-	-	-	-	-	-	-	-	-	-	77	1	8	8	38	17	434	4	51	2	947	197	25	22	2 156	5 141	-	-	-	9 126
	Heavy fuel oil	-	-	-	-	-	-	-	-	-	-	-	-	-	350	0	-	6	145	-	127	20	5	0	308	19	-	104	48	84	-	-	3 456	4 674
	Other petroleum products	-	-	-	-	-	-	-	-	-	-	-	-	-	54	90	6	85	329	-	1 211	-	-	-	-	-	-	2	131	151	-	-	1 327	3 385
	Electricity	16	10	-	3	0	0	40	4	13	59	22	11	9	-	105	431	315	387	17	1 166	388	35	367	609	246	9	839	12 762	19 737	-	-	2 237	39 836
	Heat, Geothermal, Solar Th	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	181	1 400	74	-	-	-	1 659
Other industrial sectors	Iron and steel	-	8	-	-	1	35	5	8	0	37	8	4	6	29	1	5 330	1 287	444	296	418	28	17	4 012	24	22	-	19	22 740	336	-	121	16 346	51 581
	Non ferrous metals	-	2	-	-	0	8	1	2	0	9	2	1	1	7	0	1 287	311	107	72	101	7	4	969	6	5	-	4	5 493	81	-	29	3 949	12 460
	Non metallic minerals	-	53	-	-	0	2	1	2	0	9	2	1	1	185	4	300	72	4 429	2 016	750	142	321	1 119	147	301	26	305	22 521	3 987	-	-	4 761	41 457
	Construction	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1 482	-	-	-	-	-	-	-	-	3	-	-	44 214	-	45 699
	Chemical and petrochemical	-	703	-	-	5	4	32	57	3	256	55	27	40	2 459	52	596	144	487	227	24 204	1 052	132	1 703	130	6 690	371	1 424	30 404	33 980	25 869	-	74 547	205 653
	Paper, pulp and print	-	6	-	-	0	0	1	2	0	10	2	1	2	22	0	18	4	265	61	1 393	3 404	27	191	75	158	6	1 708	14 569	4 899	-	-	6 413	33 239
	Mining and quarrying	-	1	-	-	0	14	0	1	0	2	0	0	0	2	0	2 195	530	1 263	180	1 173	121	138	79	8	117	43	705	2 513	76	-	-	627	9 790
	Transport equipement	-	5	-	-	0	0	1	2	0	7	1	1	1	16	0	32	8	41	7	49	13	8	33 749	1 853	172	2	64	17 328	64 747	142	26 006	81 526	225 782
	Transport - Sectors	-	9	-	-	0	0	3	6	0	25	5	3	4	33	1	29	7	67	33	199	28	13	80	10 974	48	4	167	20 939	25 161	2 836	-	16 453	77 128
	Agricuture and forestry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48	129	-	-	-	13 757	-	32 874	5 199	28 793	-	1 348	12 867	95 014
	Fishing	-	4	-	-	-	-	-	-	-	-	-	-	-	12	0	-	-	-	7	6	-	-	-	-	7	42	1 903	362	3 568	-	-	519	6 430
	Agri-food industry	-	9	-	-	0	0	2	4	0	16	3	2	2	32	1	76	18	55	52	2 269	306	104	139	280	6 098	75	27 956	36 229	120 103	210	-	24 876	218 917
	Composite	206	2 393	-	4	41	82	274	486	29	2 174	462	225	336	8 377	178	12 274	2 965	7 515	23 652	26 656	7 200	1 860	60 751	35 031	9 842	565	28 611	1 053 198	733 310	492 586	305 003	200 613	3 016 897
Value-added	Labour net	21	1 267	-	1	3	14	20	35	2	156	33	16	24	4 435	94	2 129	514	3 161	5 182	7 616	2 021	570	9 349	24 533	11 018	330	13 249	654 675					**4 222 607**
	Labour taxes	9	557	-	1	1	6	9	15	1	69	15	7	11	1 948	41	935	226	1 389	2 277	3 346	888	250	4 107	10 778	4 840	145	5 820	287 605					
	Oth Labour taxes	2	137	-	0	0	1	2	4	0	17	4	2	3	480	10	230	56	342	561	824	219	62	1 012	2 656	1 193	36	1 434	70 868					
	FCF	116	1 343	-	2	2	7	16	28	2	124	26	13	19	4 700	100	1 104	267	849	1 154	2 968	939	1 303	5 069	11 563	10 743	343	4 180	222 606					
	Output taxes	-6	287	-	-	2	2	11	19	1	87	18	9	13	1 006	21	272	66	409	435	1 102	278	99	1 063	1 351	-6 418	-1	1 488	55 693					
	Net Operating surplus	66	1 099	-	-2	6	3	40	70	4	315	67	33	49	3 848	82	442	107	639	2 698	4 145	107	-332	-2 547	-3 210	4 738	-90	-982	257 215					
	M	28 751	9 799	784	1 039	311	35	627	1 163	1 932	8 117	1 912	1 729	615	1 025	-	18 826	4 547	6 683	-	62 069	9 223	2 571	66 458	2 995	8 183	1 368	26 736	245 164					
Specific margins	Trade	25	-	-	107	56	16	368	654	39	2 927	623	303	452	-	-	2 493	602	9 137	-	50 314	4 062	1 184	24 640	-	19 025	2 668	55 665	-175 359					
	Transport	21	266	-	6	11	5	69	123	7	552	117	57	85	932	20	764	184	1 761	-	4 416	1 222	1 207	1 181	-30 229	1 648	124	6 133	9 316					
	Crude oil	-	-1	-	-	-	-	-	-	-	-	-	-	-	-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Natural gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Coking coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Bituminous coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Coke oven coke	-	-0	0	-	-	-5	-	-	-	-	-	-	-	-0	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Other coal products	-	-0	0	-	-	-1	-	-	-	-	-	-	-	-0	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Gasoline + biogasoline	-0	-23	-	-	-	-	-	-	-	-	-	-	-	-10	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	LPG	-0	-2	-	-	-	-	-	-	-	-	-	-	-	-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Jet Fuel	-0	-7	-	-	-	-	-	-	-	-	-	-	-	-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Diesel and biofuel	-0	-34	-	-	-	-	-	-	-	-	-	-	-	-14	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Heating fuel	-0	-13	-	-	-	-	-	-	-	-	-	-	-	-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Heavy fuel oil	-0	-6	-	-	-	-	-	-	-	-	-	-	-	-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Other petroleum products	-0	-5	-	-	-	-	-	-	-	-	-	-	-	-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Electricity	-	-460	-	-68	-	-9	-	-	-	-	-6	-27	0	-2 887	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Heat, Geothermal, Solar Th	-	-276	-	0	-	-	-	-	-	-	-0	-0	1	-25	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Iron and steel	-	-87	-	42	-0	-7	0	1	-	3	-1	-	0	-184	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Non ferrous metals	-	-24	-	0	-	-	0	2	-	3	-1	-0	11	-135	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Non metallic minerals	-	-168	-	11	-0	-	1	5	-	15	-3	-11	43	-165	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Construction	-	1	-	-	-	-	1	-	-	6	-1	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Chemical and petrochemical	-	-88	-	8	-0	-	17	159	-	165	-33	-10	-24	-498	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Paper, pulp and print	-	-96	-	1	-	-	0	3	-	5	-0	-2	-	-166	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Mining and quarrying	-	-2	-	-	-	-	1	3	-	5	-4	-0	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Transport equipement	-	-14	-	-	-0	-	1	3	-	11	-0	-0	-	-88	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Transport - Sectors	-	-3	-	-	-	-	78	0	-2	640	-72	-24	-	-146	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Agricuture and forestry	-	8	-	-	-	-	8	56	-	-749	-12	-1	-	41	0	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Fishing	-	0	-	-	-	-	-1	-	-	-100	-2	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Agri-food industry	-	-73	-	7	-0	-	3	18	-	27	-2	-8	0	-201	1	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Composite	-	-326	-	4	-0	-5	84	130	-0	823	-164	-4	17	2 149	4	-	-	-	-	-	-	-	-	-	-	-	-	-					
	SMFC	-	2 268	-	-5	-	27	-635	-33	-	-367	301	-133	-47	3 130	-5	-	-	-	-	-	-	-	-	-	-	-	-	-					
	SMG																																	
	SMI																																	
	SMX	1	-566	-	-0	0	0	441	-348	2	-488	-	220	-1	-784	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
Taxes	VAT	-	2 006	-	16	-	5	657	695	-	3 584	871	14	50	6 823	13	51	12	696	5 006	5 075	1 062	28	12 907	1 353	1 612	172	6 557	86 315					
	Tax on Energy product FC	-	275	-	-	-	-	294	149	-	6 133	320	29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Tax on Energy product IC	-	-	-	-	-	-	8 660	188	-	7 096	315	119	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
	Oth Taxes	16	232	-	12	5	0	31	55	3	246	52	25	38	813	17	27	6	46	185	723	20	42	-935	-5 593	-1 335	3	360	41 518					
	Total SUPPLY	29 246	20 470	784	1 187	1 129	426	18 642	4 551	4 421	43 026	9 126	4 674	3 385	39 836	1 659	51 581	12 460	41 457	45 699	205 653	33 239	9 790	225 782	77 128	95 014	6 430	218 917	3 016 897	**4 222 607**				

France, 2010	Energy/quasi quantities (Mtoe)	Crude oil	Natural gas	Coking coal	Bituminous coal	Coke oven coke	Other coal products	Gasoline + biogasoline	LPG	Jet Fuel	Diesel and biofuel	Heating fuel	Heavy fuel oil	Other petroleum products	Electricity	Heat, Geothermal, Solar Th	Iron and steel	Non ferrous metals	Non metallic minerals	Construction	Chemical and petrochemical	Paper, pulp and print	Mining and quarrying	Transport equipement	Transport - Sectors	Agriculture and forestry	Fishing	Agri-food industry	Composite	Public consumption	Households consumption	Investment	Export	TOTAL USES	Output	Imports	BALANCE
Energy sectors	Crude oil	-	-	-	-	-	-	17	2	5	25	10	5	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	67	2	65	-
	Natural gas	0	-	-	-	0	0	0	0	0	0	0	0	0	4	3	1	0	2	0	1	1	0	0	0	0	0	2	11	14	-	-	3	43	1	42	-
	Coking coal	-	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	3	-	3	-
	Bituminous coal	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0	2	0	0	-	0	0	-	-	-	-	-	0	0	0	-	-	0	8	0	8	-
	Coke oven coke	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	0	-	0	-	-	0	-	-	-	0	0	-	-	-	0	3	2	1	-
	Other coal products	-	-	-	-	0	0	-	-	-	-	-	-	-	0	-	0	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	0	1	1	0	-
	Gasoline + biogasoline	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	8	-	-	7	15	14	1	-
	LPG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	-	1	0	0	0	0	0	-	0	1	1	-	-	1	4	2	2	-
	Jet Fuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	0	-	-	-	5	8	4	4	-
	Diesel and biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	0	0	8	2	0	0	7	16	-	-	3	38	22	16	-
	Heating fuel	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	1	0	0	0	2	0	0	0	4	6	-	-	-	13	8	5	-
	Heavy fuel oil	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	-	0	0	-	0	0	0	0	1	0	-	0	0	0	-	-	8	11	4	7	-
	Other petroleum products	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	-	2	-	-	-	-	-	-	0	0	0	-	-	3	6	4	2	-
	Electricity	0	0	-	0	0	0	0	0	0	0	0	0	0	4	0	1	1	1	0	2	1	0	1	1	0	0	1	15	14	-	-	4	46	44	2	-
	Heat, Geothermal, Solar Th	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	0	2	0	-	-	-	2	2	-	-
Other industrial sectors	Iron and steel	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0	4	0	0	-	0	21	0	-	0	15	48	29	19	-
	Non ferrous metals	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	-	0	5	0	-	0	4	12	7	5	-
	Non metallic minerals	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1	0	0	1	0	0	0	0	16	2	-	-	3	30	23	7	-
	Construction	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	0	-	-	39	-	41	41	-	-
	Chemical and petrochemical	-	1	-	-	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	17	1	0	1	0	5	0	1	22	22	17	-	54	145	83	62	-
	Paper, pulp and print	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	1	12	3	-	-	5	27	18	9	-
	Mining and quarrying	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	1	0	0	0	0	0	0	1	2	0	-	-	0	7	5	3	-
	Transport equipement	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	2	0	0	0	15	49	0	20	72	188	122	66	-
	Transport - Sectors	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	31	36	4	-	23	112	109	3	-
	Agriculture and forestry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	11	-	26	4	22	-	1	10	74	66	8	-
	Fishing	-	0	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	0	0	-	-	-	-	0	0	1	0	2	-	-	0	3	2	1	-
	Agri-food industry	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4	0	20	26	80	0	-	18	150	123	27	-
	Composite	0	2	-	0	0	0	0	1	0	2	0	0	0	9	0	13	3	8	25	28	7	2	63	36	10	1	30	1 097	721	484	300	212	3 055	2 810	245	-

France, 2010 - Prices (€/toe)	Crude oil	Natural gas	Coking coal	Bituminous coal	Coke oven coke	Other coal products	Gasoline + biogasoline	LPG	Jet Fuel	Diesel and biofuel	Heating fuel	Heavy fuel oil	Other petroleum products	Electricity	Heat, Geothermal, Solar Th	Iron and steel	Non ferrous metals	Non metallic minerals	Construction	Chemical and petrochemical	Paper, pulp and print	Mining and quarrying	Transport equipement	Transport - Sectors	Agriculture and forestry	Fishing	Agri-food industry	Composite	Public consumption	Households consumption	Investment	Export
Crude oil							436	436	436	436	436	436	436																			458
Natural gas	329				329	329	329	329	329	329	329	329	329	329	329	329	329	329	476	329	329	408	408	408	476	476	408	408	725			201
Coking coal					238	238																										238
Bituminous coal														132	172	172	172	172		172	172						172	172	172			132
Coke oven coke																386		386		386			386				386	386				386
Other coal products					329	329								329		329												112	779			387
Gasoline + biogasoline																1 430	1 430	1 430	1 430	1 430	1 430	1 430	1 430	1 430	1 430	663	1 430	1 430	1 711			663
LPG																1 076	1 076	1 076		1 076	1 076	1 076	1 076	917	1 076		1 076	1 076	1 425			469
Jet Fuel																								532				532				532
Diesel and biofuel																1 135	1 135	1 135	1 135	1 135	1 135	1 135	1 135	1 099	698	627	1 135	1 135	1 357			512
Heating fuel														596	596	596	596	596	596	596	596	596	596	596	604	596	596	596	835			
Heavy fuel oil														409	409		409	409		409	409	409	409	409	419		409	409	428			450
Other petroleum products														526	526	526	600	600		512							600	600	532			512
Electricity	580	580		580	580	580	580	580	580	580	580	580	580	-	580	504	504	504	865	504	504	727	580	580	865	865	580	865	1 451			518
Heat, Geothermal, Solar Th																									684		684	684	769			

6.3 Appendix 3: formulary of the 'KLEM' model of section 0

We successively detail the production of the aggregate energy and composite resources, final consumption and investment, international trade, price formations and market clearings. Variable names indexed with a '0' designate the specific values calibrated on 2010 benchmark data; they thus indicate parameters of the equation system. Whenever required, good-specific variables are indexed by *E* for the energy good, by *C* for the composite good.

6.3.1 Production of the aggregate resource

The input trade-offs of each production (energy and the composite good) are represented as nested structures of Constant Elasticity of Substitution functions (*cf.* Figure 3-1 p.5). At each tier of these structures, standard cost minimisation defines the consumption of any input *A* traded off with another input B (capital *K* and labour *L*, value-added *KL* and energy *E*, *KLE* aggregate and composite input *α Y* or domestic output *Y* and imported variety *M*) to produce some aggregate *AB* (value-added *KL*, *KLE* aggregate, domestic output *Y* or total resource *Q*) as

$$A = \left(\frac{\alpha_{AB}}{p_A}\right)^{\sigma_{AB}} \left(\alpha_{AB}^{\sigma_{AB}}\, p_A^{1-\sigma_{AB}} + \beta_{AB}^{\sigma_{AB}}\, p_B^{1-\sigma_{AB}}\right)^{\frac{\sigma_{AB}}{1-\sigma_{AB}}} AB\ , \tag{1}$$

with σ_{AB} the central elasticity parameter (*cf.* values reported Table 3-1 p.11); α_{AB} and β_{AB} coefficients calibrated on benchmark 2010 data; p_A and p_B the purchaser prices of good *A* and *B*.

6.3.2 Final consumption and investment

The consumed income of households *R* is the sum of primary factor payments and taxes, *i.e.* Gross Domestic Product (GDP), net of public expenses $p_G\, G$, investment $p_I\, I$ and the trade balance $p_X\, X - p_M\, M$:

$$R = GDP - \left(\textstyle\sum_i p_{G_i} \mathrm{G}_i + \sum_i p_{I_i} I_i + \sum_i p_{X_i} X_i - \sum_i p_{M_i} M_i\right) \tag{2}$$

Households' utility is a constant elasticity of substitution function of their consumptions of the energy and composite goods, H_E and H_C. Facing prices p_{Hi} and elasticity σ_u, utility maximisation induces:

$$H_i = \left(\frac{\alpha_U}{p_{H_i}}\right)^{\sigma_U} \left({\alpha_U}^{\sigma_U}\, {p_{H_E}}^{1-\sigma_U} + {\beta_U}^{\sigma_U}\, {p_{H_C}}^{1-\sigma_U}\right)^{\frac{\sigma_U}{1-\sigma_U}} R \tag{3}$$

Public spending G_i is a constant share s_{Gi} of GDP (traditionally nil for energy goods *i.e.* $s_{GE} = 0$)

$$p_{G_i} G_i = s_{G_i} GDP \tag{4}$$

Investment has a constant ratio s_{Ii} to consumed income, amounting to a constant savings rate (of course $s_{IE} = 0$):

$$p_{I_i} I_i = s_{I_i} R \tag{5}$$

6.3.3 International trade

Following the Armington specification of international trade (Armington 1969), the trade-off between domestic production *Y* and imports *M* is settled by a CES function—the upper tier of the production function of aggregate resource introduced above. *Y* and *M* thus follow the general form of (1). Exports X_i are defined as elastic to terms-of-trade:

$$X_i = X_{i_0} \left(\frac{p_{X_i}}{p_{M_i}} \frac{p_{M_{i_0}}}{p_{X_{i_0}}} \right)^{\sigma_{X_i}} \quad (6)$$

For lack of a better assumption both σ_{Xi} are set to 1.

6.3.4 Market clearings and accounting identities

Market balance for each good i equates total resource Q_i to the sum of intermediate consumptions α_{ij} Y_j, household consumption H_i, the consumption of public administration G_i, the consumption for investment I_i and the exports X_i:

$$Q_i = \sum_j \alpha_{ij} Y_j + H_i + G_i + I_i + X_i \quad (7)$$

Labour and capital demand by the two productions i sum up to total exogenous labour supply L and capital endowment K (through the adjustment of wage w and rent p_K):

$$\sum_i L_i = L \quad (8)$$

$$\sum_i K_i = K \quad (9)$$

6.3.5 Producer and Purchaser Prices

The cost of labour p_L is equal to the net wage w plus payroll taxes levied at a constant rate τ_{CS}:

$$p_L = (1 + \tau_{CS}) w \quad (10)$$

The price p_{AB} of any CES aggregate AB (value-added KL, KLE aggregate, domestic output Y, total resource Q) is the standard function of prices p_A and p_B:

$$p_{AB} = \left(\alpha_{AB}^{\sigma_{AB}} \, p_A^{1-\sigma_{AB}} + \beta_{AB}^{\sigma_{AB}} \, p_B^{1-\sigma_{AB}} \right)^{\frac{1}{1-\sigma_{AB}}} \quad (11)$$

An exception, p_Y adds to this generic form a constant *ad valorem* output tax τ_Y p_Y.

International prices p_{Mi} are fixed (the international composite good is the *numéraire* of the model; the price of imported energy relative to that of the international composite good is constant).

The purchaser's price of good i consumed in the production of good j (p_{ij}), by households (p_{Hi}), by public administrations (p_{Gi}), in investment (p_{Ii}) or by exports (p_{Xi}) is the sum of: its resource price p_{Qi}; a constant, agent-specific, *ad valorem* margin τ_{SM}; an exogenous, agent-specific excise tax t; an exogenous, agent-specific *ad valorem* sales tax τ:

$$p_{ij} = \left(p_{Q_i} \left(1 + \tau_{SM_{ij}} \right) + t_{ij} \right) (1 + \tau_{ij}) \quad (12)$$

$$\forall \, A \in \{H, G, I, X\} \;\; p_{Ai} = \left(p_{Q_i} \left(1 + \tau_{SMA_i} \right) + t_{Ai} \right) (1 + \tau_{Ai}) \quad (13)$$

All tax and excise rates are calibrated on benchmark data (*cf*. Table xx p. xx). Calibrating on non-hybridised matrices mechanically induces nil values for all τ_{SM}, *i.e.* prices are only differentiated by explicit tax differences across agents. The energy quotas simulated in section 0 use the t excises (on firms or household consumptions only, or on both agents simultaneously) as variables to comply with consumption cuts targets.

6.3.6 Accounting aggregates

GDP is the sum of factor payments and taxes T:

$$GDP = \sum_i w\, L_i + \sum_i p_K\, K_i + T, \tag{14}$$

while *T* is the sum of taxes levied of labour, productions and consumptions:

$$T = \sum_i \tau_{CS}\, w\, L_i + \sum_i \tau_{Yi}\, p_{Yi} Y_i + \sum_i \sum_j \frac{\tau_{ij}}{1+\tau_{ij}} p_{ij} \alpha_{ij} Y_j$$
$$+ \sum_i \sum_j t_{ij} \alpha_{ij} Y_j + \sum_{A=H,G,I,X} \sum_i \frac{\tau_{Ai}}{1+\tau_{Ai}} p_{Ai} A_i. \tag{15}$$