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Hybrid Accounting Methods for Sustainable Development Modelling

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The report is structured as follows. Section 2 summarizes the key features that a Sustainable Development or "Green Growth" model should contain. On this basis, Section 3 discusses the rationale and the state-of-the-art of elaborating hybrid accounting systems that are necessary to represent the material content of growth trajectories in a way that is consistent with economic accounting. Section 4 presents the specific method for elaborating hybrid accounting that we propose to use in the context of this project.

1. The material content of Green Growth trajectories

Following the seminal papers of (Solow, 1974) and (Stiglitz, 1974) and with the appearance of notions like 'limits to growth' and 'sustainable development', the Energy-Environment-Economy nexus has been the subject of intense work. In particular, general equilibrium models based on the "growth engine" of the Solow model have been developed to demonstrate the possibility and identify the conditions of long-term growth paths compatible with resources constraints and environmental cycles. But most numerical models are limited when it comes to representing the problems caused by deviations from balanced growth pathways, because they adopt the standard assumptions of perfect foresight and flexible technico-economic adjustments. This limit was underlined by Solow himself in his Nobel Prize lecture (Solow, 1988) and is all the more important when large deviations from the current energy and material content of growth are considered.

To model growth trajectories in the course of green transitions, one must thus go beyond the exogenous growth drivers conventionally considered in the Solow model (demography and productivity) and introduce a whole range of additional processes. First, one must model imperfect expectations and market failures that affect technical change and prevent the full exploitation of the exogenous growth potential. Second, one must capture the existence of several sectors that differ in terms of labor, material and resource intensities, and endogenize the structural change across these sectors. Finally, one must account for the fact that the adaptation of consumption patterns and of production processes has limitations due to technical and behavioral inertias.

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The above recommendations impose to describe capital heterogeneity, sources of market inefficiencies and technical/organizational inertias, all of which cannot be pictured without a quantitative description of the material content of development trajectories. As a prerequisite, one must thus capture the many possible “physical” contents (in terms of energy, labor, machines, etc.) that can underlie a given growth path described in monetary terms. And one must endogenize the interplays between these “physical contents” (both on the production and on the consumption side) and the growth engine. From a methodological point of view, this imposes to go beyond the standard Social Accounting Matrixes—which describe the economy through monetary flows only—to adopt hybrid accounting schemes that ensure the consistency between monetary flows and physical flows. Unfortunately, consistent matrixes describing monetary and physical flows are typically unavailable from statistical agencies. One must thus create a method to construct such matrix by extending national accounts to incorporate information from different fields of expertise (engineering, economics, sociology, etc.). The next sections of this report present the rationale of this hybrid approach and propose a technical solution to build a consistent physical / monetary accounting scheme suited to analyze Green Growth.

2. Hybrid accounting methods for Green Growth modeling

This section presents the two complementary purposes of hybridization, namely to improve the representation of technical change (section 2.1) and to correct economic flows to ensure the consistency between monetary and physical flows (section 2.2). Section 2.3 reviews the methodologies already described in the literature to meet these aims (section 2.3). These discussions are illustrated by numerical examples derived from the elaboration of the IMACLIM-France model.

2.1. Controlling technical change in numerical models

A good representation of technical change is essential to green growth modeling. Technical change, indeed, drives the changes of production possibilities over time. Two main ways of representing technical change coexist in the literature.

The **technico-economic approach** is based on an explicit and detailed representation of technical systems. It is in an engineering-based vision of production and consumption processes. Technico-economic studies are generally focused on a single sector (e.g., energy, transportation, construction, agriculture, etc.), the physical, technological and economic dimensions of which are represented in details. Technico-economic studies typically aim at identifying in details the possible innovations in a given sector, and at evaluating the cost and benefits of their implementation. Particular attention is paid to the dynamics of the transition process and in particular to the speed of diffusion of new technologies given information on the lifetime of equipment, of infrastructure and of production capacities, the expected evolution of demand, etc. Aggregate costs and benefits of technical options can be derived by summing up "bottom-up" the effects of the implementation of each option in each sector.

Macroeconomic analysis, on the other hand, is based on a stylized and aggregated representation of technical systems, but it incorporates them into a comprehensive view of mutual interdependences that characterize the functioning of the economy. Efforts have been made to represent endogenous technical change induced by prices as innovation depends not only from sources of sectoral technical progress (R & D, learning by practice, etc..), but also from intersectoral interactions that determine, in particular, , investment potentials and final demand from households and other sectors (input-output accounting). In other words, technical change in macroeconomic analysis is no longer a phenomenon limited to a sector, but a systemic phenomenon constrained primarily by the nature of the relationship between supply and demand on markets. In macroeconomic analysis, finally, the physical content of economic processes and the complementarity/substitution effects in response to variations of relative input prices (productive capital, labor and intermediary consumption like energy) are typically represented with an aggregate production function, the functional form and parameters of which are often assumed constant over time.

Technico-economic and macroeconomic analysis are not opposite. Rather, they illustrate two different focuses on the same question. The former provides important details on technical systems, but it simplifies the representation of economic interactions by considering sectors independently from their context, thus not capturing macroeconomic effects. The latter adopts a comprehensive description of macroeconomic interplays, but with stylized representations of technologies in aggregated production functions. Combining the advantages of both representations, "hybrid" bottom-up/top-down models have been developed to synthetize information on technical and economic determinants of structural change (Hourcade et al. 2006). The energy-climate modeling community has been particularly active in this direction, as demonstrated by a number of recent works (among others, IPCC, 2007, Edenhoffer et al. 2010, or Luderer et al. 2012).

But two key limitations remain. First, using an aggregated production function that is invariant over time prevents the analyst from representing changes in cost structure due to technical change. Second, the methodologies adopted to estimate the parameters of aggregate production functions do not guarantee consistency between monetary and physical quantities over time (Ayres and Warr, 2009). In fact, whatever their mathematical form, aggregated production functions are calibrated on cost-shares data through Shepard's lemma[1]. This operation comes down to assuming that, at each point of time, installed technologies result from an optimal response of firms to the current price vector. This methodology is valid for marginal deviations from current production trends, but it becomes questionable for large deviations, such as the large decoupling between production and resources that green growth forces us to consider. To represent large-scale technical change under resource constraints, one must adopt an explicit accounting of the physical constraints that weigh on the evolution of technologies.

To explicitly account for the physical constraints that weigh on the evolution of technologies, one needs a "hybrid" accounting system which tracks both monetary and physical flows and ensures the consistency between the two, not only at the calibration date but also at point in time. This procedure allows one to overcome the two limitations outlined above. First, production processes can now be explicitly described in physical terms. It is no longer necessary to use the device of an aggregate production function in monetary terms. Second, with a hybrid accounting system, it becomes much easier to translate into the model available information on the constraints that weigh on technical change. The dialogue between economists and engineers is facilitated.

[1] Shephard's lemma states that the cost minimizing point of a given input (X) with price (P_X) is unique. The idea is that the producer will buy a unique ideal amount of each item to minimize the price for obtaining a certain level of production given the price of goods in the market.

2.2. Correcting material flows at the calibration date

The principles and manipulations by which one can derive a system of coherent statistical tables from physical data and various monetary sources are not standardized. Standard macroeconomic models, although based on the axiomatic of the Arrow-Debreu principle—i.e., the dual representation of the flow of goods and services in the economy in quantities and values—are built exclusively on monetary data drawn from national accounts - sometimes synthetized in the form of a "social accounting matrix”. Quantities are not described in physical units but are deducted from the monetary data under the assumption of a normalized shadow price. To construct a correct hybrid accounting system, one needs to go beyond this standard procedure by collecting and processing additional data from various sources (engineering, sectoral data, etc.) and by ‘merging’ them with social accounting matrixes, in a process described below. Although it might be viewed as an obstacle at first glance, this improved but more complex calibration process actually reinforces the validity of the datasets that are finally used in the model as different sources of data are now incorporated.

The macroeconomic impact of green growth policy depends crucially on the initial description of the material flows in the economy. For example, the effect of the implementation of a carbon price depends on the initial weight of energy expenditure in the GDP and on the distribution of energy expenditure between sources for sectors and households. Moreover, the income and price elasticity of energy consumption of these agents are estimated from data on the share of energy costs in production costs and in consumer budgets. Yet different statistical sources yield significantly different pictures of energy flows, energy expenditures and carbon emissions, even in developed, statistically-rich economies. We illustrate this on the case of France in 2004

Concerning energy flows, a gap persists between the value published by national accounts and the value that can be calculated by using energy sector data (precisely, by multiplying energy flows by energy price data). The French input-output table gives a total value of energy consumed in the country in 2004 as 142 Billion euros (INSEE, 2006). But multiplying sectoral data on prices and quantities from the International Energy Agency (IEA) yields only 101 Billion euros (Table 1). Depending on the figure selected, a very different view of the economic weight of fossil energy sectors in the French economy emerges (4.8% instead of 3.4%). The discrepancy between the two figures stems from the fact that in national accounts nomenclatures, the energy sector includes, besides fuel production, a large number of other activities with high value-added (e.g., petroleum products). The sector as seen by national account is thus much larger than direct fuel production, though it is only the latter that will be affected by a carbon tax.

Table 1. Economic value of fossil energy flows

	French National Accounts (Input-Output tables, 116 sectors)		Energy statistics, IEA (material balance and prices)	Statistical gap
	Energy branches (nomenclature NES)	2004 value (million euros)	2004 energy expenditures* (millions euros)	
Coal	Coal, lignite and peat	1 965	1 558	26%
Crude Oil	Hydrocarbures	26 875	17 234	56%
Petroleum products	Refined	92 974	67 454	38%
Gas and Heat	Gaseous fuels, heat and air conditioning	20 229	15 230	33% (*109%*)
	Mineral chemistry	*(11 596)*		
Fossil energy ***(incl. Mineral chemistry)***		**142 043** ***(153 639)***	**101 476**	**40%** ***(51%)***
Share in production ***(incl. Mineral chemistry)***		**4,8%** ***(5,2%)***	**3,4%**	**1,4%** ***(1,8%)***

* Sources: IEA (2006, 2007)

A similar discrepancy in the data occurs for energy expenditures, which differ markedly depending on whether they are derived from national accounts or from survey data on households' income and expenditures (Table 2). The discrepancy is partly due to the statistical methods used in households' surveys. Precisely, the samples in the survey are constructed so that the samples are representative of key macreconomic variables (such as demography or revenues). But the samples of households may not be constructed to be representative of energy consumption patterns.

Table 2. Households' energy expenditures

2001 Energy expenditures (Million euros)	**National accounts**	**Households' survey**	**Statistical gap**
Fuels, lubricants and liquefied petroleum gas	30 443	26 913	**13,1%**
Gas and electricity	22 322	19 312	**15,6%**
Oil	4 600	7 394	**-37,8%**

Source: INSEE (2006)

The total amount of carbon emissions is close in all datasets but the sectoral classification of emitters differs whether it estimated from input-output tables or energy statistics (Table 3). In the first case, carbon emissions are attributed to production activities and final consumption by associating a certain amount of emissions to each energy purchase (*cf.* Miller et Blair, 2009 ; Moll *et al.*, 2007). In the second case, only energy statistics in physical quantities are mobilized and carbon emissions are calculated directly from the carbon-to-energy content.

Table 3. French CO_2 emissions, by activity

	Calculated value from energy statistics	**Official value ***	**Statistical gap**
Total emissions (MtC)	109 107	111 904	-2,5%
Production emissions *(Households' emissions)*	67 846 *(41 261)*	76 095 *(35 809)*	-10,8% *(+15,2%)*
Residential emissions *(Private vehicles emissions)*	16 127 *(25 134)*	17 289 *(18 520)*	-6,0% *(34,8%)*

Source: Pasquier (2010)

This section has demonstrated that even for France—a country in which statistics are very reliable and extensive—macroeconomic datasets and material balances are not consistent and may in fact present important discrepancies. The gap between national accounts and information drawn from sectoral sources is likely to be wider in countries in which statistics are more difficult to collect, for example because of the informal economy as in South Africa. This calls for a careful attention to data collection and processing in order to identify the most reliable sources on which to build the hybrid matrix.

2.3. Hybridization methodologies: state-of-the art and diagnostic

Characterizing a hybridization methodology comes down to identifying which variables are fixed at their raw value in existing datasets (we refer to these as 'fixed variables') and which variables are modified to offset statistical gaps while maintaining accounting identities ('adjusted variables'). The existing methods of hybridation can be distinguished according to the choice of fixed and adjusted variables, and according to the technical processes used to make the adjustments.

In what follows, we consider three methodologies in details to illustrate the necessary tradeoffs to have to be made in the process of elaborating hybrid systems. These methodologies are already in use in the context of world Energy-Environment-Economy models like EPPA (Paltsev et al., 2005), GEMINI-E3 (Bernard and Vielle, 2003) and SGM (Fawcett and Sands, 2005).

Most hybridization methods start from the Global Trade Analysis Project (GTAP) database, which has the advantage of providing harmonized national accounts for all regions of the world. This database has then been modified as the GTAP-E database to introduce external information on volumes and prices associated to bilateral energy flows. More precisely, the methodology consists in using energy prices to convert bilateral trade flows of energy from a value base to a volume base, reconciling the derived energy volume trade flows with the total volume contained in the volume data base, reconverting the (reconciled) volume trade flows into value trade flows using the energy price and the margin information from GTAP and putting this energy trade flow back into the GTAP trade flow matrix (Malcolm and Truong, 1999). The statistical error is then reported on domestic value added and energy quantities (Mc Dougal and Lee, 2006), which has the drawback of introducing some important deviations in the local use of energy. For example, Sands et al. (2005) report for version GTAP 5.0 (1997) that the above-described adjustments lead to a 50% error on the value added of the power sector in China or to a 37% increase of coal inputs for electricity production in the same country.

To overcome this limitation that is very detrimental when considering energy and/or climate policies, a second methodology leading to a new database GTAP-EG has been developed. This methodology aims at preserving energy quantities and price statistics (Rutherford et Paltsev, 2000). In this case, statistical gaps are reported on the value added of energy sectors to maintain accounting identities, which implies a modification of GDP levels.

Finally, the methodology developed for the *Second Generation Model* (SGM) is different in nature because it consists in developing a specific database to overcome the distortions noted with GTAP (Sands et al, 2005). The general principle consists in keeping the value added of energy sectors and the physical quantities, and in calculating consistent average price levels for each energy (independently from its use) to maintain accounting consistency. This methodology avoids the most important biases identified above by ensuring a correct accounting of both local energy flows and aggregate GDP levels. However, it suffers from two limitations. First, it ignores the heterogeneity of purchase prices according to consumers (Table 4) despite its importance to picture the differentiated effect of energy/climate measures on different types of agents. Second, energy flows are identified with the production value of energy branches from national accounts, which, given the weight of non-energy products in these activities, comes down to overestimating energy flows and the economic value of carbon emissions.

From this analysis and the comparison of the different existing methods, we can derive some recommendations for the choice of the hybridization methodology to be employed for the representation of Green Growth trajectories in the IMACLIM framework (Table 5). First, the correction of statistical gaps must be carried out in such a way that the size of the economy (measured by GDP) and domestic energy flows are preserved. This means imposing quantities and value added for all energies. Second, price heterogeneities must be represented to capture the different sensitivities of energy consumption according to the activity considered. This is particularly important for electricity and gas prices, which are partly administered in several regions of the World. Finally, the description of the material content of economic activities is preferably derived by synthetizing information from different expert sources, which has the advantage of reinforcing the validity of aggregate estimates reconstructed from the aggregation of information at a very detailed level. In addition, this approach gives more flexibility to adapt the level of aggregation of the description to the singularity of the economy under consideration.

Table 4. Purchase prices under different hybridization methods

2004 euros/toe, all taxes included	**Homogeneous prices***	**Differentiated prices ****		
		Industrials	**Electricity producers**	**Households**
Coal	140,67	99,37	84,85	831,06
Crude Oil	305,40	223,00	-	-
Petroleum products	766,37	557,42	383,09	1028,90
Electricity	881,18	466,26	-	1325,43
Gas and Heat	475,53	229,00	221,51	510,27

* source: IEA (2006)
** source: IEA (2007)

Table 5. Summary and comparison of different hybridization methods

Hybrid database	Sources (values / quantities)	Fixed variables	Adjusted variables
GTAP-E	International* (GTAP / IEA)	None	GDP Energy quantities Energy value added Energy prices
GTAP-EG	International* (GTAP / IEA)	Quantities Energy prices	GDP Energy value added
SGM	National or International	Quantities Energy value added	Energy goods prices
IMACLIM	National or International	Energy quantities Energy prices	Non-energy sectors value (GDP conserved)

3. Hybridization procedure for Green Growth assessments

3.1 General principles

A hybridization methodology adapted for the representation of Green Growth trajectories must permit to follow in parallel input-output tables and their consistent counterpart in terms of material flows, still respecting two basic principles. First, both physical and money descriptions must respect the conservation principle, namely that each use presupposes the availability of the resource and conversely that each resource must be used (possibly transformed or stocked). Second, physical and money flows are linked by a system of prices and the total economic value associated to the production, trade or consumption of each good is given by the product of an aggregate volume times a price.

These principles can be formalized mathematically as a system of accounting identities, as follows:

$$\forall\ i, \quad \sum_E Q_{i,E} = \sum_R Q_{i,R} \quad \text{Supply and use balance (quantities)}$$

$$\forall\ i, \quad \sum_E V_{i,E} = \sum_R V_{i,R} \quad \text{Supply and use balane (values)}$$

$$\forall\ (i,o), \quad V_{i,o} = P_{i,o} * Q_{i,o} \quad \text{Consistency between quantities, values and prices}$$

$$\forall\ (i,o), \quad CO2_{i,o} = \varepsilon_{i,o} * Q_{i,o} \quad \text{Physical consistency (carbon balance)}$$

With : i, index of economic operation

Q, quantities (in physical units, e.g., Mtoe for energy)

V, values (in monetary units, M€)

R, set of operations linked to resources (production, importation, stocking…)

E, set of operations linked to uses (consumption, investment, exportation…)

P, set of prices associated to each type of exchange

CO2, CO_2 emissions

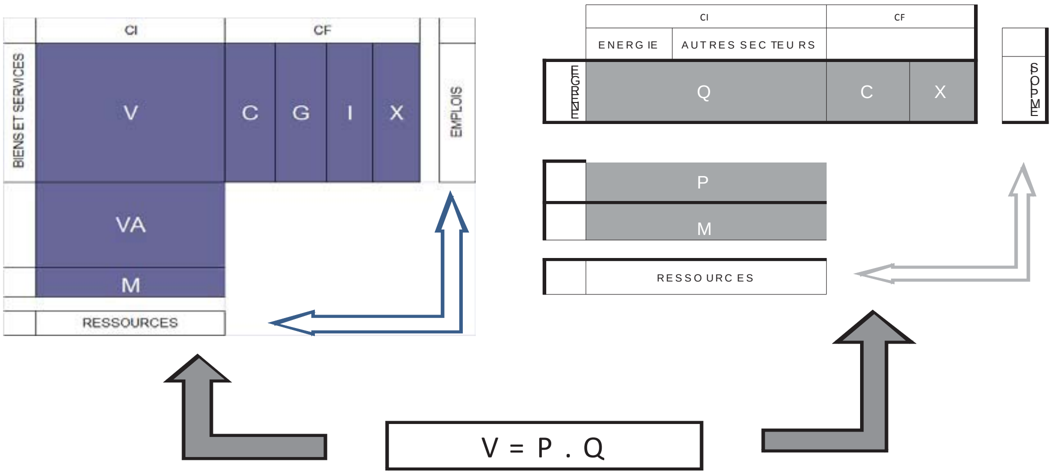
We will call « hybridization procedure » the set of manipulations necessary to ensure the consistency between macroeconomic data from national accounts and datasets from material balances and/or tangible physical indicators, and to allow reconstituting a hybrid picture of the economy at a calibration date.

To illustrate the hybridization methodology developed at CIRED, we concentrate on energy flows as the unique material flows to be harmonized. They are given in standardized *energy balances* which detail the processes of energy production, transformation and consumption measured according to their energy content expressed in Mtoe. This type of statistical system makes it possible to reorganize datasets in a supply-use format similar to the one adopted for national accounts: uses include energy intermediary consumption of productive sectors (Q) and final consumptions (C, X) whereas supply concern volumes produced (P) and imported (M).

The second component of the procedure is supply-use tables in monetary values, which are built as follows: columns give resources distinguished between intermediate consumption in monetary value (V), value added (VA) and imports (M), while rows detail uses distinguished between intermediary consumption (V), final consumption by households (C) and public administration (G), gross fixed capital formation (I) and exports (X).

The hybridization procedure consists in organizing the dialogue between the energy balance in the supply-use format and supply-use tables in monetary values (Figure 1).

Figure 1. Matrix representation of accounting equilibrium in values and quantities



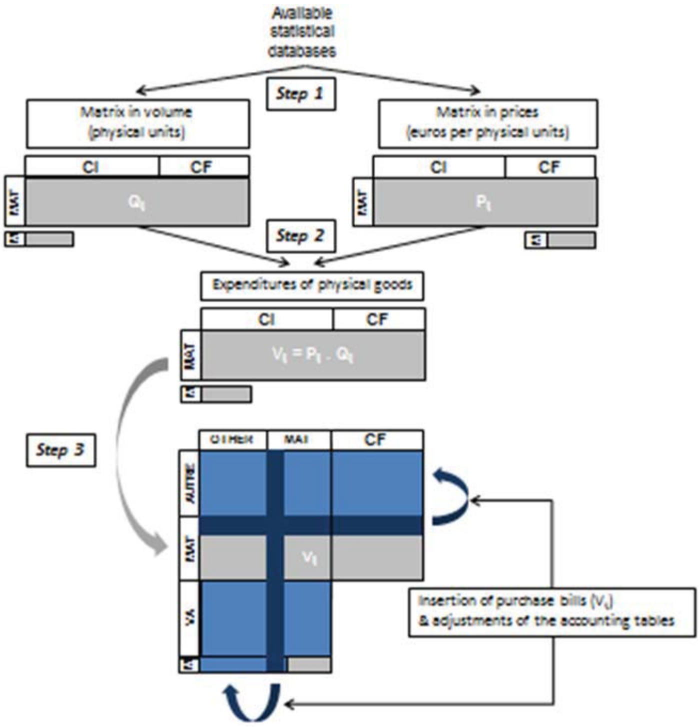
Once the raw datasets have been collected and processed, the hybridization procedure comprises three steps. This is done by reporting the difference between the "energy bills" and the statistics in the non-energy composite sector (Figure 2). Although this methodology is illustrated on energy balance, it can be directly extended to other material flows:

(1) The first step consists in producing, from specialized statistics, the tables in the right format to summarize and gather the information available on material flows. In the specific case considered here, they are energy balances in volumes (Mtoe) and energy prices (euros/Mtoe)

(2) The second step consists in reconstituting the "energy bills" (in euros) at the same level of disaggregation by multiplying tables in volumes and prices on a one-to-one basis.

(3) The third step consists in plugging this matrix of energy values into the system of national accounts and to adjust the other components to maintain the accounting identities without modifying total value added of domestic production. This is done by reporting the difference between the "energy bills" and the statistics from the "energy branch" into the non-energy composite sector.

Figure 2. Overview of the hybridation procedure



The next sections enter more into the technical detail of each step and illustrate them on the example of France for 2004.

3.2 Step #1: Elaborating supply-use tables in physical units

Since tables of resources and uses for physical flows and prices are not available from statistical institutes in a standardized 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 for the sake of simplicity (Table 6), we can identify domestic production (line 1), international trade (line 3-4), transformation processes (limited to refining in this simplified example- line 5) and the distribution of final consumption across activities (line 9-12).

Table 6. Simplified structure of the IEA energy balance

Quantities (**Million ton oil-equivalent ,Mtoe).**	A- Crude oil*	B- Other commercial energies (coal, electricity, petroleum products, natural gas)	C- Non-commercial energies (biomass and waste)	**Total**
1- Production	-	55	10	**65**
2- Imports	87	88	-	**176**
3- Exports	-	-29	-	**-29**
4- Marine bunkers	-	-3	-	**-3**
Total Primary Energy Supply	**87**	**111**	**10**	**209**
5- Transformations	-87	83	-	**-5**
6- Losses		-5	-	**-5**
7- Feedstocks		2	-	**2**
Total Final Consumption	**-**	**191**	**10**	**201**
9- Road Transport	-	**52**	1	**53**
10- Buildings	**-**	**77**		**77**
11- Other sectors	**-**	**47**	**9**	**56**
12- Non-energy uses	**-**	**15**	**-**	**15**

Source: IEA (2006)

Difficulties of the transformation from the energy balance in Table 6 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 road transport (line 9) and buildings (which mix residential and tertiary-line 10), and the neat decomposition for these two activities is dependent upon the availability of complementary datasets (e.g., transport and 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: 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 (-11% of refining inputs and -4% of natural gas supply)

Sub-step 1.2: 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.

Sub-step 1.3: aggregating and allocating quantities of the energy balance in Figure 4 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.

Table 7 illustrates the effect of the manipulations in sub-steps 1.1 and 1.2 on the original energy balance presented in Table 6.

Table 7. Energy balance after sub-steps 1.1 and 1.2

Quantities (Million ton oil-equivalent ,MTOE).	A- Crude oil	B- Other commercial energies	**Total**
1- Production	-	55	**55**
2- Imports	77	83	**160**
3- Exports	-	-29	**-29**
4- Marine bunkers	-	-3	**-3**
Total Primary Energy Supply	**77**	**106**	**183**
5- Transformations	-77	73	**-4**
6- Losses		-5	**-5**
7- Feedstocks		2	**2**
Total final consumption	**-**	**176**	**176**
9 - Road transport (households)	-	**23**	**23**
10- Road transport (sectors)		**29**	**29**
11- Residential	**-**	**38**	**38**
12- Tertiary		**39**	**39**
13- Other sectors	**-**	**47**	**47**

These 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, CO2 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

3.2 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 8). This table is fully consistent with the energy statistics on the diversity of rates, energy consumption, carbon content, etc.

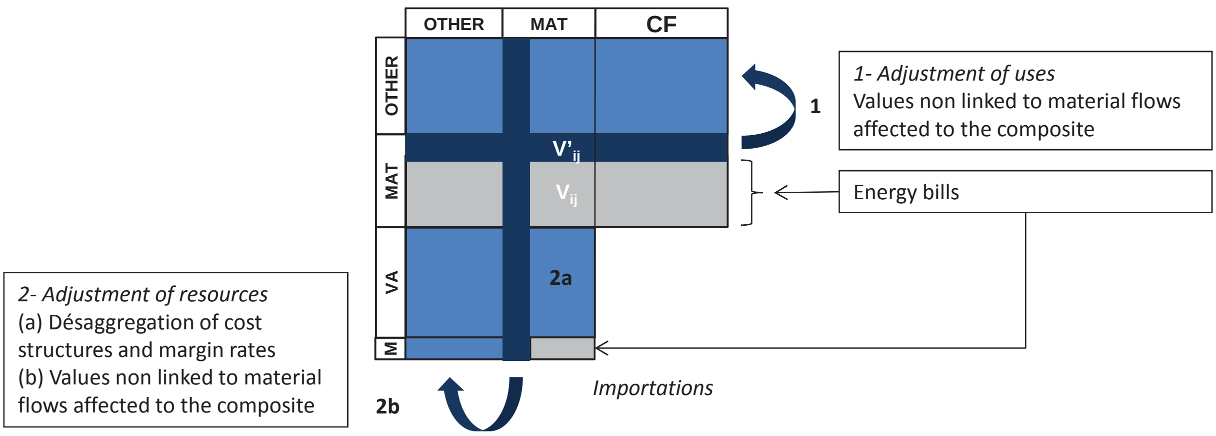
Table 8. The balance of energy bills

Billion euros	Products			Final uses		Total uses
	Composite	Crude Oil	Final energies	Final demand	Exports	**Total uses**
Primary energy	-	-	17	-	-	**17**
Final energy	35	-	11	65	7	**118**
Imports		17	16			

3.3 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 hybridization step as such (Figure 3) 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 3. 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 hybridization process, we consider the case of France and start from input-output tables obtained from National Accounts (Table 9).

Table 9. Input-Output tables in National Accounts

Billion euros		Products			Final uses			**Total uses**
		Composite	Primary energy	Final energy	Final consumption	GFCF	Exports	
Products	Composite	1 350	-	27	1°272	321	414	**3°384**
	Primary energy	-	-	26	-	-	-	**26**
	Final energy	66	-	21	63	-	12	**162**
Value added		1 453	-	35				**3 572**
Total production		2 869	-	109				
Imports		385	26	13				
Taxes on production		130	-	40				
Total resources		**3 384**	**26**	**162**	**3 572**			

Sub-step 3.1: adjustments of uses. Starting from input-output in national accounts (Table 9), we replace the values of energy branches (lines 2 and 3) by the values of reconstructed energy bills (orange, Table 10). Differences are added to uses and imports of composite (dark blue: first-line and first-line sixth column). These operations do not affect the total value of uses (3572), but change those of different products. Therefore, the supply-use balances are broken.

Table 10. Step 1

Billion euros		Products			Final uses			Total uses
		Composite	Primary energy	Composite	Primary energy	Composite	Primary energy	
Products	Composite	1 410*	-	17*	1°270	321	419	**3°437**
	Primary energy	-	-	17	-	-	-	**17**
	Final energy	35	-	11	65	-	7	**118**
Value added			-	35				**3 572**
Total production			-	80				
Imports			17	16				
Taxes on production			-	40				
Total resources			**17**	**136**	**3 572**			
Resources - Uses		***-18***	***0***	***18***				

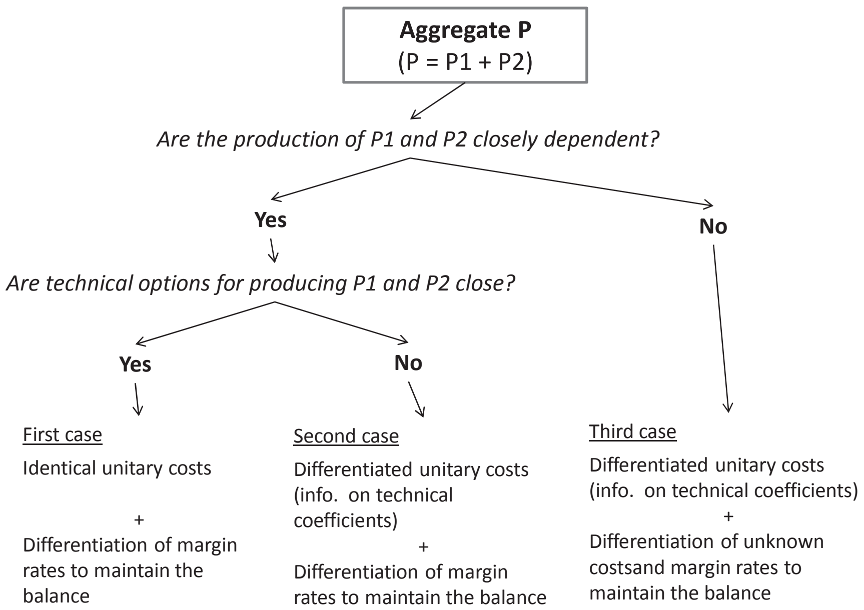
Sub-step 3.2: adjustment of resources. Balances between uses and resources are restored by manipulating the cost structure of industries (columns TES). Values of imports and intermediate consumption are given by the energy statistics and other cost components - value added, margins, taxes on products - are adjusted to restore equality of resources with uses (Table 10). Since, in our example, energy taxation is known (8th-line third column), 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.

Table 10. Step 2

Billion euros		Products			Final uses			Total uses
		Composite	Primary energy	Composite	Primary energy	Composite	Primary energy	
Products	Composite	1 410	-	17	1°270	321	419	**3°437**
	Primary energy	-	-	17	-	-	-	**17**
	Final energy	35	-	11	65	-	7	**118**
Value added			-	18[c]				**3 572**
Total production			-	63				
Imports			17	16				
Taxes on production			-	39[a]				
Total resources			**17**	**118**	**3 572**			
Resources - Uses			***0***	***0***				

It is useful to keep in mind some principles to guide the choice of adjusting resources (substep 3.2). We can offer a procedure to select the set of assumptions to be used to isolate the cost structures of two products (Figure 10) 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 4. 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.

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