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NET ENERGY ANALYSIS OF OIL AND NATURAL GAS PRODUCTION IN BRAZIL – USING THE MUSIASEM APPROACH

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ABSTRACT
This study analyses the energetic performance of the Oil and Gas sector of Brazil using the MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) approach. In this approach, the performance of the energy sector is assessed using the concept of "Strength of the Energetic Hypercycle" described by the ratio of two vectors: (i) the supply of the mix of energy carriers delivered to society (the mix of outputs); (ii) the consumption of the mix of energy carriers used by the energy sector (the mix of inputs). The results of the study show that this method of accounting provides an effective quantitative characterization of the set of energy transformations taking place in the energy sector of Brazil. In fact, it makes it possible to describe the requirement of labor and energy carriers (defined in type and quantity) of the different compartments of the society. Moreover, this method of accounting makes it possible to bridge two types of information referring to: (i) "typologies" – technical coefficients describing the performance of a process studied in terms of unitary operations at the local scale (bottom up information); and (ii) "instances" – statistical data describing aggregated quantities of energy flows associated to a mix of energy transformations taking place in functional compartments (top down information). This distinction between "bottom-up" and "top-down" information is simply not available when adopting the conventional method of accounting of energy statistics.

INTRODUCTION

Despite Brazil's large output of biofuel (particularly ethanol from sugarcane) and ample hydroelectric generation, in 2013 fossil energy represented the principal source of energy in Brazil - more than 50% of total primary energy. In 2013, the production of petroleum and natural gas (biophysical) was equivalent to 2,6 million barrel/day (EPE, 2014). About 85% of this production was done in offshore areas, mostly of them concentrated in deep and ultra-deep water.
This study analyses the energetic performance of the Oil and Gas (O&G) sector in Brazil using the MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) approach (Giampietro et al. 2013). The MuSIASEM accounting scheme is based on a pre-analytical definition of categories for energy accounting based on the acknowledgment that different energy forms cannot be summed. More specifically, MuSIASEM makes two key distinctions:
1) a distinction between "primary energy sources" and "energy carriers". i) "Primary Energy Sources" are quantities of energy referring to primary energy. Primary Energy Sources are forms of energy generated by processes outside human control – e.g. fossil energy, solar energy, wind energy. ii) "Energy Carriers" are quantities of energy referring to secondary forms of energy generated by processes under human control powered by Primary Energy Sources;
2) a distinction between "thermal energy" and "mechanical energy": the qualitative difference between these two forms of energy has been flagged by the pioneers of thermodynamics: 1 Joule of thermal energy is different in "quality" from 1 Joule of mechanical energy. As a matter of fact,

modern energy sectors sacrifice large quantities of Joules of thermal energy (in the form of fossil energy) to produce smaller quantities of Joules of electricity (a form of mechanical energy).
In conclusion, when describing in quantitative terms the transformations taking place in the energy sector we should expect to use at least 4 different categories of accounting: (i) PES thermal (e.g. fossil energy); (ii) PES mechanical (e.g. hydro or wind); (iii) EC thermal (e.g. fuels); and (iv) EC mechanical (e.g. electricity).When analyzing the set of transformation of the Oil and Gas (O&G) sector in Brazil, by definition, we deal only with the category of PES thermal on the input side – both oil and gas belong to this category – and with two categories of EC on the output side: EC thermal (fuels) and EC mechanical (electricity). The transformation of a given quantity of Primary Energy Source thermal (oil and natural gas) into an energy product consumed by the society – Energy Carriers either fuel or electricity – can be described in four steps: (i) extraction of the PES thermal; (ii) transportation of the PES thermal (oil and gas); (iii) processing PES into EC (refining); and (iv) transportation of the EC thermal (final distribution of fuels). Each one of these four steps requires the consumption of a mix of energy carriers (different types of fuels and electricity). Then it concludes comparing the results obtained by adopting this method with the results given by official statistics.

MuSIASEM Approach

The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) is an innovative method of accounting making it possible to integrate quantitative information generated by distinct types of conventional data and referring to different dimensions and scales of analysis. The approach can be applied to characterize in quantitative terms several types of flows associated with the metabolic pattern of societies (food, energy, water, waste). This flexibility is due to the adoption of "grammars" as opposite to models (Giampietro et al. 2013; Diaz-Maurin, 2013) that make it possible to define a "meta-scheme" of accounting based on semantic categories. An illustration of the MuSIASEM grammar applied to the analysis of the energy sector is given in Figure 1.

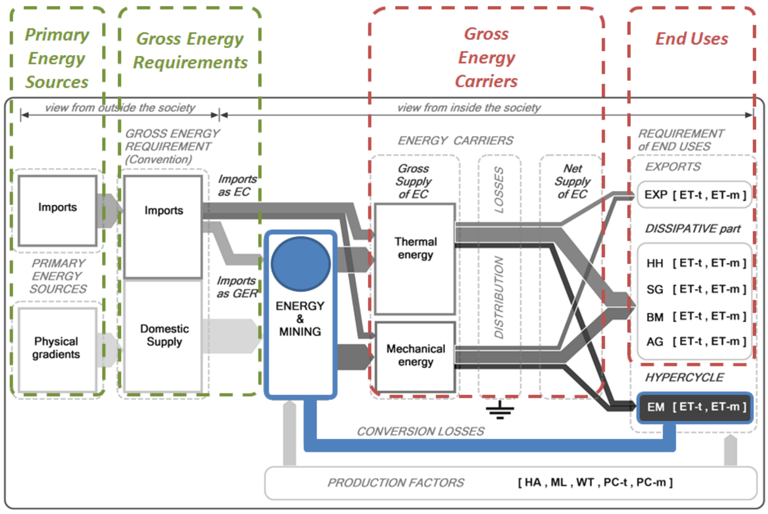

Figure 1: Energy grammar by MuSIASEM
Source: Giampietro et al,, 2014

The grammar makes it possible to describe: (i) the level of opennes of the black-box interacting with its context – i.e. imports, exports, domestic production, gross consumption; and (ii) the network of transformations describing the working of the parts within the black-box – i.e. gross throughput (overall flow), losses, net throughput in each one of the functional elements, fraction of the gross input needed for the internal autocatalytic loop (e.g. energy carrier used to make energy carriers). Therefore, with this approach the metabolic pattern is characterized by combining two views:
(1) the external view (on the left) makes it possible to check, measuring quantities of energy in PES, the factors determining the severity of external constraints: (i) availability of resources determined by processes outside human control limiting domestic supply (e.g. lack of natural resources); and

(ii) processes taking place outside the boundary making available the imports (e.g. the cost of the imports);
(2) the internal view (on the right) makes it possible to check, measuring quantities of energy in EC thermal or EC mechanical, the factors determining the internal constraints. In this way we can study the processes under human control taking place within the boundary of the system (the technical coefficient of individual processes) and the fraction of the total energy transformations that is required for the operations of the energy sector itself (the energy carriers consumed to generate energy carriers). In first approximation, the society is composed of four functional compartments (described by vectors): i) Household (HH); ii) Service and Government (SG); iii) Building and Manufacturing (BM); iv) Agriculture and Fishing (AG).To which we have to add an other vector describing the consumption of energy carriers going in to the functional compartment Energy and Mining (EM) itself. In the jargon of MuSIASEM the quantity of energy carriers consumed by the energy sector itself to generate a net supply to the rest of the society is called the "hypercycle".
In this way, the MuSIASEM accounting makes it possible to calculate a characteristic of the energy sector using the concept of "Net Energy Analysis". More specifically the relation over the two vectors of end uses: (i) one describing the mix of gross supply of energy carriers – the output of the energy sector; and (ii) one describing the mix of requirement of energy carriers consumed by the energy sector itself – the input of the energy sector; is called the Strength of the Energy Hypercycle (SEH) (Giampietro et al, 2013).

The characterization of the domestic supply from the Oil and Gas Sector

The external view focuses on the amount of PES (biophysical supply) that the domestic sector is producing for Brazil. In this case, the two PES considered are: (i) tonnes of oil; and (ii) m of natural gas; both belonging to the category "thermal". The internal view focuses on the network of energy transformations carried out in four functional compartments of the O&G sector: (i) exploration and production (extraction) PES; (ii) transport of PES; (iii) refinery and processing PES → EC; and (iv) deliver EC to the final consumers. Different inputs are required to operate these four functional compartments. Using the jargon developed in the MuSIASEM approach we can divide these inputs in: (i) flows – inputs of energy carriers (e.g. gasoline, diesel, bunker fuels, electricity); (ii) funds – inputs of hour of labor, and use of technology. The outputs of the O&G sector is a mix of energy products such as gasoline, diesel, fuel oil, jet fuel which are used by the other economic sectors, for example, residential, commercial, transportation, etc. A representation of this taxonomy of categories of energy flows is given in Table 1.

Table1: Accounting categories external and internal view

External view (biophysical)	Internal view	
Primary Energy Sources - PES	TRANSFORMATION	END USE
OIL & GAS	GASOLINE	HOUSEHOULD
	DIESEL	SERVICE/GOVERNMENT
	COKE	BUILDING/MANUFCTURE
	HEATING OIL	AGRICULTURE/FISHING
	JET FUEL	ENERGY/MINING
	OTHERS	

An overview of this accounting scheme is given in Fig. 2. For each one of these four steps the Oil and Gas sector uses a mix of different technological solutions (processes). For example, in the functional compartment #2 (transport of the PES) oil transportation is done using a combination of: (i) pipelines, (ii) barges/ships; and (iii) trucks. These technological solutions can be characterized using technical coefficients in terms of a profile of consumption of different inputs – described by a vector of quantities such as hours of labor, fuels (diesel, bunker fuel, natural gas) and electricity per k-ton of oil transported (output).

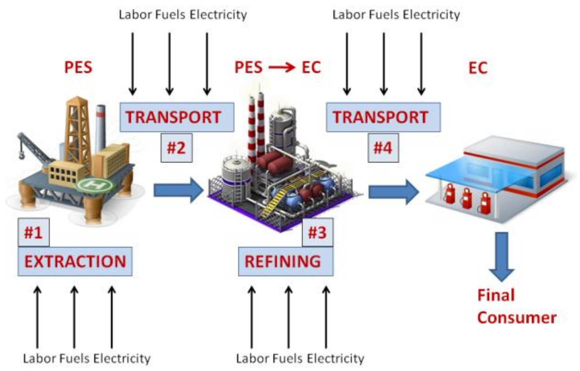

Figure 2: The four functional compartments of the Oil and Gas sector and their requirement of inputs

Analysis of the four compartments

Exploration and Production – E&P

For the activity of exploration and production E&P of oil and natural gas we organized the data in relation to two different technical processes: (i) onshore; and (ii) offshore areas referring to five types of platform (fixed, FPSO, explorer ship and semi submersible). This distinction is necessary because the two technical processes – extraction on land and at sea – are described by vectors of end uses describing the use of production factors (labor, electricity and fuels) completely different. The inputs of energy carriers are represented by oil products, natural gas and electricity. The consumption of oil products is basically diesel for electricity. This implies that the input of electricity can come: (i) by auto production, by diesel and natural gas; or (ii) purchased direct from the grid. Table 2 shows the use of energy carries, in PJ, by the E&P activity in Brazil in 2010

Table2: Exploration and Production – energy input (PJ)

ACTIVITY	PRODUCTION FACTORS					
E&P	ENERGY CARRIERS (PJ)					
	Oil products		Natural Gas		Electricity	
	thermal	eletr*	thermal	eletr*	thermal	eletr**
ONSHORE	**6,2**	**1,7**	**23,5**	**6,4**	**0,0**	**0,9**
FIXED	6,2	1,7	23,5	6,4	0,0	0,9
OFFSHORE	**31,8**	**8,6**	**123,9**	**33,5**	**0,0**	**4,5**
FIXED PLATFORM	17,9	4,8	69,7	18,8	0,0	2,5
FPSO	8,5	2,3	33,2	9,0	0,0	1,2
EXPLORER SHIP	0,8	0,2	3,2	0,9	0,0	0,1
SEMI SUBMERSIBLE	4,6	1,2	17,8	4,8	0,0	0,6
TOTAL	**38,0**	**10,3**	**147,5**	**39,8**	**0,0**	**5,4**

Note: FPSO - floating production, storage and offloading. * Auto production, ** from the grid

Transport (from the oil and natural gas fields)

For the activity of transport of O&G from the fields to the processing centers (refineries and natural gas plants) we organized the data in relation to three technical processes: (i) pipelines; (ii) ships and barges; and (iii) coast/cabotage and long-distance/oversea. Since the production is concentrated at sea areas, most of the transportation is made by ships and barges, which covers a coastline of 7.500km. The mix of inputs of energy carriers include: (i) marine fuels for boats/barges – diesel; (ii) marine fuel bunker (mix of diesel and residual fuels) for ship; and (iii) natural gas for pipeline. Table 3 shows the use of energy carries, in PJ, by the transport activity in Brazil in 2010.

Table3: Transport from the fields to the conversion plants- energy input (PJ)

ACTIVITY	PRODUCTION FACTORS					
TRANSPORT	ENERGY CARRIERS (PJ)					
	Diesel Fuel		Residual Fuel		Natural Gas	
	thermal	eletr*	thermal	eletr*	thermal	eletr*
PIPELINES					**1,8**	**0,6**
Oil & GN					1,8	0,6
SHIP/BARGES	**2,3**		**6,9**			
Cabotage (coastal)	0,6		1,8			
Oversea	1,7		5,1			
total	**2,3**	-	**6,9**	-	**1,8**	**0,6**

Note: * Auto production, ** from the grid

Conversion Plants (refineries)

For the activity of transforming the PES of O&G into EC products we organized the data in relation to three typologies of technical processes relative to the size of the plant: (i) small – processing less than 20 k-m /day; (ii) medium - processing between 20-50 k-m /day; and (iii) large - processing more than 50 k-m /day. For the Natural Gas Plants: (i) small - processing less than 5 Mm /day; (iii) medium - processing between 5-10 Mm /day; and (iii) large - processing more than 10 Mm /day. The mix of inputs of energy carriers to support this activity includes: (i) oil products (fuels); (ii) natural gas; and (iii) electricity. The oil products are basically distillate or residual fuel oils. Also in this case electricity there is a distinction between the electricity that comes from auto production (using oil products), and that purchased direct from the grid. Table 4 shows the use of energy carries, in PJ, by the conversion center activity in Brazil in 2010.

Table4: Conversion plants- energy input (PJ)

ACTIVITY	PRODUCTION FACTORS					
TRANSFORMATION	ENERGY CARRIES (PJ)					
	Oil products		Natural Gas		Electricity	
	thermal	eletr*	thermal	eletr*	thermal	eletr**
REFINERIES	**180,8**	**5,6**	**53,7**	**1,7**	**-**	**7,0**
Small < 20 K m^3 / day	90,4	2,8	26,8	0,8	-	3,5
20 <Medium < 50 Km^3 / day	79,1	2,4	23,5	0,7	-	3,1
Big > K50 m^3 / day	11,3	0,3	3,4	0,1	-	0,4
NATURAL GAS PLANTS	**-**	**-**	**53,4**	**14,4**	**-**	**1,5**
Small < 5 Mm^3 / day	-	-	34,3	9,3	-	1,0
5 <Medium <10 Mm^3 / day	-	-	11,4	3,1	-	0,3
Big > 10 Mm^3 / day	-	-	7,6	2,1	-	0,2
total	**180,8**	**5,6**	**107,1**	**16,1**	**-**	**8,5**

Note: * Auto production, ** from the grid

Distribution

For the activity of distribution of EC products from the conversion plants to the end use we organized the data in relation to three technical processes: (i) pipeline, (ii) ship/barges and (iii) trucks. The mix of inputs of energy carriers for this activity includes: (i) marine fuels (bunker) for ship; (ii) natural gas for pipeline; and (iii) diesel fuel for trucks. Table 5 shows the use of energy carries, in PJ, by the distribution activity in Brazil in 2010.

Table5: Distribution - energy input (PJ)

ACTIVITY	PRODUCTION FACTORS					
TRANSPORT	ENERGY CARRIERS (PJ)					
	Diesel Fuel		Residual Fuel		Natural Gas	
	thermal	eletr*	thermal	eletr*	thermal	eletr*
PIPELINES					**1,3**	**0,4**
Oil Products					1,3	0,4
SHIP/BARGES	**2,3**		**6,3**			
Cabotage (coastal)	0,6		1,6			
Oversea	1,7		4,7			
TRUCKS	**88,8**					
total	**91,0**	**-**	**6,3**	**-**	**1,3**	**0,4**

Note: * Auto production, ** from the grid

Organzing the quantitative analysis across hierarchical levels

In table 6 we show an overview of the results presented in the previous tables. In this table we include also a very rough estimation of the labor input (hours per year) to the different functional sectors. As these data was not studied as deeply as the energy data, this input does not want to provide a reliable assessment of the work requirement in the O&G sector in Brazil. However, it can be used as a first proxy to illustrate a special feature of the MuSIASEM methodology.

Table6: Matrix of "end-uses" in the O&G sector – energy and labor inputs

		Required mix of inputs vector of end-uses			
		Labor	ENERGY CARRIERS		Autoprod.
		Mhours	PJ-therm	PJ-electr	PJ-electr
Functional compartments	E&P	238	185	5	50
	Transport (PES)	81	11		1
	Transformations	57	288	9	22
	Transport (EC)	250	99	-	0
	TOTAL	626	484	14	73

At this level of aggregation these numbers cannot be used to study the role that the performance of the technologies used in the sector play in determining the performance of the whole system. For this reason we re-organize these data using a more complex hierarchical organization making possible the scaling of information across different levels (Fig. 3). Considering the first raw of data in Fig. 3 we have that 38 Mhours of labor, 29.772 GJ of fuels and 870 GJ of electricity have been required in the technical process "on shore" (compartment Extraction) to supply 12.000.000 m of oil.

year 2010	CONSUMED INPUTS			PES throughput				FUNCTIONAL
	Mhr	GJ fuel	GJ electr	m³ oil/year			MIX	COMPARTMENTS
On shore	38	29.722	870	12.000.000	∑	118.000.000	10%	EXTRATION
Off shore	200	155.767	4.487	106.000.000			90%	
Pipeline	10	1.768	-	70.000.000	∑	118.000.000	59%	TRANSPORT TO REFINERY
Ships	25	9.142	-	48.000.000			41%	
Small	28	151.580	4.485	17.000.000			15%	
Medium	25	114.037	3.387	75.500.000	∑	118.000.000	64%	REFINERY
Large	3,5	22.285	657	24.800.000			21%	
Pipeline	3	1.292	-	29.500.000			25%	
Ships	22	8.576	-	14.750.000	∑	118.000.000	12%	TRANSPORT TO END USES
Trucks	225	88.779	-	73.750.000			63%	

Fig. 3 Quantitative analysis of inputs/outputs from statistical data organized

At this point, we can divide the quantities of inputs consumed by the different technical processes by the throughput of PES processed (for example, 38 Mhours of labor/12.000.000 m). In this way, we can obtain an assessment of quantities of inputs required per unit of throughputs and calculate a vector of end uses typical of this technical process – in yellow in Fig 4. That is, remaining in this example we can say that the technical process "on shore" can be characterized by using the following vector: 3,2 (hr/m3); 2,5 (GJ-fuel/m3); 0,1 (GJ-electr/m3) referring to a throughput of 12.000.000 m of oil (PES). These end-uses vectors (in yellow) define the specific mix of inputs (labor and energy carriers) required per unit of output processed by the technical processes. The different values of throughputs of the different technical processes are expressed as a combination of two values: "throughput of on shore" (12.000.000 m³ oil/year) can be expressed as the fraction (10%) of the "throughput of Extraction" (118.000.000 m³ oil/year).

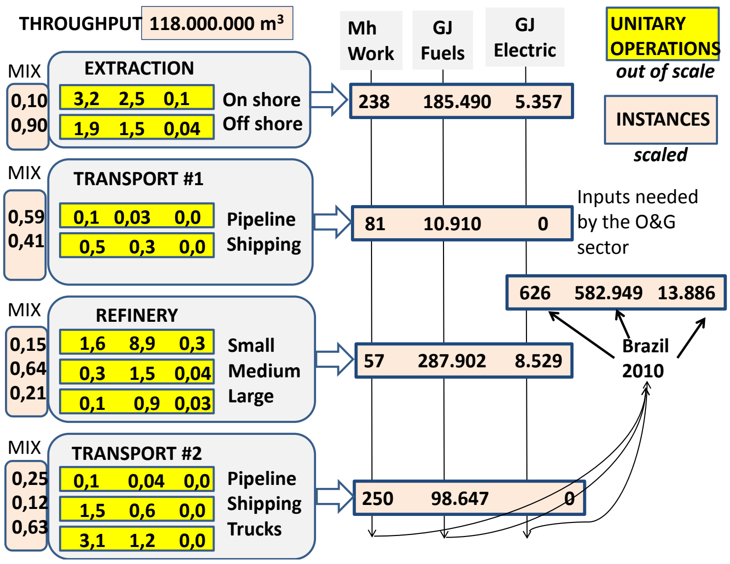

Fig. 4 Quantitative analysis of inputs/outputs from technical data referring to unitary Operations (bottom-up)

By adopting this way of expressing number we can establish a bridge between quantitative assessment referring to different hierarchical levels and therefore scale information. "Bottom-up information" referring to the characteristics of technical processes studied in terms of unitary operations, can be interfaced with "top-down information" referring to characteristics of whole functional sectors gathered through statistical data.

CONCLUSION

In this paper we presented the preliminary results of an attempt to implement a multi-lelve accounting of the a compartment of the energy sector of Brazil – the O&G sector. The organization of the accounting of inputs and outputs over the different functional compartments of the O&G sector of Brazil presented here shows that it is possible to:
(i) explain the factors determining the overall performance of the sectors across different levels of analysis: the profile of inputs and outputs of the whole O&G sector are determined by the profile of inputs and outputs of each one of the four functional compartments and their relative importance. In cascade, the profile of inputs and outputs of each functional compartment is determined by the profile of inputs and outputs of the technical solutions adopted for expressing the specific task of the functional compartments and their relative importance; (ii) make comparisons of the efficiency of the specific energy subsectors of Brazil with analogous subsectors operating in other countries by individuating what are the factors determining the differences at which level – i.e. the technical coefficients assessed on unitary operations, a different mix of technologies, a different use of the different technologies; (iii) make scenarios of possible changes by assuming changes in technological coefficients of technological solutions or changes in the mix of technological solutions in the different steps or changes in the relative importance of the steps.

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