Naphtha Production Assessment from the Perspective of the Emergy Accounting

G. Bustamante(✉), B.F. Giannetti, F. Agostinho, Márcia Terra da Silva, and C.M.V.B. Almeida

Paulista University, São Paulo, Brazil
gustamante1000@hotmail.com, cmvbag@unip.br

Abstract. Naphtha is the main petroleum derivative used as a feedstock for the steam cracking of olefins and aromatic petrochemical products. The environmental performance of the production of 1 kg of naphtha is evaluated using a Life Cycle Inventory-based emergy accounting, considering the environmental load of labor and services. The biophysical flows, which reflect the work of nature in the creation of the resources required for the production and the monetary systems, are evaluated in terms of emergy. The information recorded in a life cycle inventory (LCI) is used for the estimation of the specific emergy of naphtha. The results show that labor and services flows correspond to 10.54% and 12.93% of the total system emergy, respectively. The LCI-based emergy accounting, although being an unconventional measurement method, was found feasible bringing additional information that may help decision making.

Keywords: Emergy · Specific emergy · Environmental accounting · Petroleum fuels · Oil refining · Naphtha

1 Introduction

When production systems are analyzed by conventional methods for decision making, the monetary flows related to the purchase of goods and services (materials, energy, labor, infrastructure) are often the only components taken into account. The economy bestows values upon these resources, in monetary terms, such as prices, which only correspond to the payments made for services in production, extraction, processing and delivering of these products in the global market. However, money does not pay for the resources provided by nature and prices are just the value that different market participants directly or indirectly grant to human services required by the production processes [1].

Currently, different methods and measurement tools are used to assess the environmental burdens caused by the intensive extraction and use of renewable and non-renewable resources by the production systems. Still, only few tools, such as emergy accounting, can reflect in a common unit (solar equivalent joules, seJ) the value of the biophysical and monetary flows of a production system. This measurement tool includes into formal accounting the contribution of

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natural ecosystems for producing the raw materials used up by human systems, quantifying all production costs in comparable physical units [2].

Campbell and Tilley [3] determined the value of the goods and services provided by nature based on emergy flows. They estimated the economic values for the ecological work, and called these values "eco-prices", which were defined as the emergy flow of an ecosystem service for the estimated amount of money flowing in countercurrent. Given the importance of the petroleum-based production systems, which use massive amounts of non-renewable resources, Bastianoni et al. [4] determined the specific emergies (seJ/g) of oil and natural gas, according to their geological production process. Later, in [5], these authors determined the emergy per joule (transformity) for liquid petroleum several derivatives, and quantified the cost structure of two refineries in emergy terms.

This article assesses the emergy flows of naphtha production, including those related to labor and services, using data obtained from the life cycle inventory (LCI) of naphtha production chain. The emergy of labor and services reflects the support required by the human labor directly and indirectly involved in the production processes. The results that combine environmental and economic information may help decision making [6,7].

2 Method

Odum [8] defined emergy as the amount of available energy of a kind required, directly or indirectly, to obtain a product (good or service) or of an energy flow required by a process. Emergy is expressed in solar energy joule (seJ), which is the common basis of all energy flows within the biosphere. The higher the total emergy, the greater the amount of solar energy previously contained, processed and consumed by an input flow. The emergy intensity coefficients, known as transformities (seJ/J), can be calculated as the ratio of solar energy, directly or indirectly required to produce a joule (J) of another type of energy.

The emergy accounting method [8] is applied to assess the energy inflows that make up the transformation process required to produce naphtha, and to determine the unit emergy value (UEV, seJ/g) of the product (Eq. 1). Transformities and UEVs can be considered as a measure of the process efficiency.

$$EM = \sum_{k=1}^{n} EM_k = \sum_{t=1}^{n} Tr_k \times En_k \quad (1)$$

Where EM is the total emergy of the system; EMk is the emergy of the input k; Trk is the transformity or UEV of the same input flow and; Enk, the energy used to obtain a specific flow.

The appropriate way of accounting for labor and services linked to the production processes by applying emergy is related to that described by Ulgiati and Brown [1], in detail. These authors proposed alternatives to calculate the emergy flows when there is no local information about the different levels of training and education. Thus, the emergy values of labor are determined by means of payments in the form of salary, multiplied by the UEV of money or the emergy to money ratio (EMR, seJ/GDP), in a year and a specific economy. An average of the European's EMR (seJ/€) in 2008 was used to determine both the emergy of labor and services (indirect labor inputs). In this case, it was assumed that wages represent education levels, training or experience of employees [1], and, as mentioned earlier, the price of the goods only reflects the value of human activities related to extracting and producing and not to the good or resource by itself.

The EMR is the emergy value of money for a country or region. It corresponds to the total emergy required to generate the Gross Domestic Product (GDP), and is measured in seJ/currency.

2.1 Data Source

Inputs data were taken from Eco-profiles documents, which are part of the Eco-profile Program and Environmental Product Declaration (EPD) of the European Association of Plastics Manufacturers, PlasticsEurope[1]. These documents are LCIs that take into account the life cycle of the product from "cradle to gate", i.e. from the extraction of raw materials, to the product ready for transport or transfer to the consumer. The inventories contain the mass and energy flows that enter the system, regarding the functional unit: 1 kg of product "at gate", and represent the average European production. The input flows have been tracked back throughout the system to its source in nature, including upstream processes as needed. The result of this tracking is the accounting of all elementary flows, so that the only economic or transformed flow is the output: 1 kg of naphtha [9].

3 Results and Discussion

The input-output flow diagram of the naphtha production (Fig. 1) shows all elementary flows that enter the system, according to the LCI (Table 1). Direct labor and services, are also included, and, their emergy measures are estimated by salaries and input prices, respectively.

The emergy analysis allowed determining the UEV of naphtha and the representativeness of each emergy inflow contributing to the total emergy, with and without labor and services. The results without services assess technological aspects and can be used for comparison with other naphtha production systems. The results, including labor and services, are site-specific and, therefore, should not be compared with systems outside the European region. The contribution of labor and services is equivalent to 10.54% and 12.93%, respectively. Services refer to the "background" processes or those out of operational control that contribute to the total emergy of the analyzed system.

The LCI-based specific emergy of naphtha without labor and services (4.75×10^9 seJ/g) is similar to the value of 5.02×10^9 seJ/g determined by

[1] Details about the Eco-profiles methodology, interpretation and data collection can be found at: http://www.plasticseurope.org/plastics-sustainability-14017/life-cycle-thinking-1746/eco-profiles-programme.aspx.

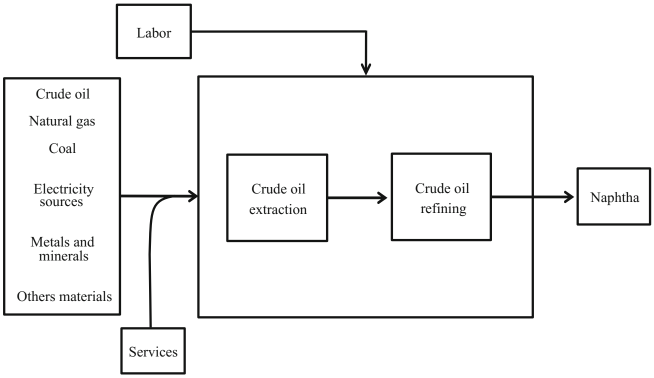

Fig. 1. Input-output flows of the naphtha production system

Sha et al. [10], who took as reference the transformity estimated by Bastianoni et al. [5] for petroleum liquid fuels (1.12×10^5 seJ/J) and multiplied by the calorific value of naphtha (44.5 kJ/g). Therefore, the specific emergy estimated in this study can be applied in the evaluation of downstream processes of the production chain, such as production of petrochemicals, resins and plastics.

Figure 2 shows the emergy contribution of the main inputs required for the production of naphtha. As shown in Table 1, crude oil, which is the main feedstock and energy source to the system, has the largest emergy contribution (with or without labor and services).

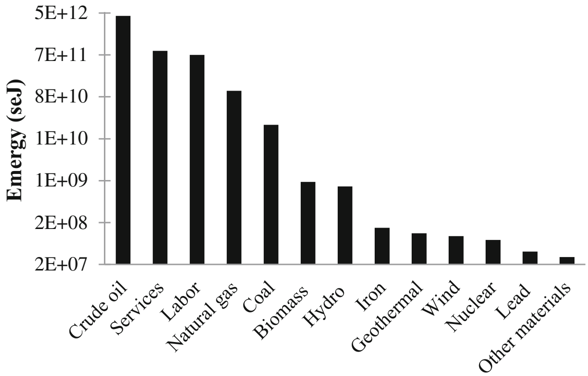

Fig. 2. Emergy contribution of the main inputs required for the production of naphtha

Table 1. Solar emergy required to produce 1 kg of naphtha.

Inputs		Quantity	Unit	Transformity or UEV*		Solar emergy (seJ)	% of emergy (without L&S)	% of emergy (with L&S)
1	Crude oil	4.80E+01	MJ	9.45E+04	seJ/J	4.54E+12	95.62	73.18
2	Natural gas	1.62E+00	MJ	6.83E+04	seJ/J	1.11E+11	2.33	1.79
3	Coal	3.57E-01	MJ	5.71E+04	seJ/J	2.04E+10	0.43	0.33
4	Hydro	7.16E-03	MJ	1.35E+05	seJ/J	9.65E+08	0.02	0.02
5	Nuclear	2.36E-01	MJ	1.60E+11	seJ/g	67300000	0.00	0.00
6	Biomass	1.77E-02	MJ	6.75E+04	seJ/J	1.20E+09	0.03	0.02
7	Geothermal	2.07E-04	MJ	4.52E+05	seJ/J	9.36E+07	0.00	0.00
8	Wind	8.28E-04	MJ	9.90E+04	seJ/J	8.19E+07	0.00	0.00
9	Iron	1.03E+01	mg	1.20E+10	seJ/g	1.23E+08	0.00	0.00
10	Lead	7.90E-02	mg	4.80E+11	seJ/g	3.79E+07	0.00	0.00
11	Other materials					2.89E+07	≈0	≈0
12	Labor	1.32E-01	€	4.97E+12	seJ/€	6.54E+11		10.54
13	Services	1.61E-01	€	4.97E+12	seJ/€	8.02E+11		12.93
Output								
14	Naphtha	1.00E+03	g	6.21E+09	seJ/g	6.21E+12		

*Transformities used for calculating the emergy of inflows, except for labor and services, were obtained from the literature and related to the baseline 15.83×10^{25} seJ/year [11]. The EMR corresponds to the weighted average of these countries by 2008.
Lines 4–8: sources of electricity used along the production chain.
Line 11: other materials corresponding to 43 elementary flows recorded in the LCI.
Line 12: the average salary of 10 European countries with highest naphtha production in 2008.

4 Conclusions

The use of LCI databases in this research has led to reliable UEV results for naphtha, according to the comparison with previous literature studies. The results show that Life Cycle Inventory-based emergy accounting is a practical and feasible way to account for the emergy of production systems. The evaluation of the technological aspects (without labor and services) proved to be useful to account for the contribution of energy and resources in the production of naphtha, and to provide reliable data for the decision making process. The results can be applied to decide for a given type of technology taking into account the environmental cost of each input flow. The inclusion of direct and indirect labor (labor and services, respectively) allowed quantifying the influence of the market, the level of training, experience and skills of workers in the production of naphtha in Europe. These results can be applied to decide upon the market (or region) in which a given type of technology may be implanted.

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