Ecological Engineering 106 (2017) 392–399

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

The solar transformity of heat and power in coproduction

Sha Sha[1], Markku Hurme*

Aalto University, Department of Chemical and Metallurgical Engineering, P.O. Box 16100, 00076 Aalto, Finland

ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form 8 June 2017
Accepted 9 June 2017
Available online 15 June 2017

Keywords:
Emergy
Heat
Power
Coproduction
Biopower
Transformity
Allocation

ABSTRACT

Emergy analysis is a method for environmental accounting which presents the solar energy footprint of products. Processes with multiple products involve special calculation rules. If the co-products cannot be produced separately, the total input emergy is allocated on both products. Therefore an inseparable coproduction is penalized by the method. Yet, if the product can be produced separately in the system, the input emergy can be split for the products.

Combined heat and power production (CHP) is a typical multi-production process, which is designed to meet the needs for the heat and power both. In earlier cogeneration emergy studies heat and power were treated as inseparable byproducts. As a result the transformity of electricity was often lower than the transformity of steam, which is not logical. Neither the approach could describe the co-production benefits to the independent production.

Different alternatives of CHP are elaborated in this paper from emergy perspective. It was found that heat & power can be coproduced semi-independently employing condensing turbines with steam reduction but not by back pressure turbines. Therefore emergy allocation is possible only in condensing turbine systems. The choice of allocation method depends on the scope and purpose of study. Efficiency based allocation methods are recommended for general and local studies.

As a case study two types of biomass CHP plants were analyzed. Work and alternative production emergy allocations were employed. In the reduction type of coproduction the transformities were the same as in independent production. Therefore no coproduction benefits were gained in this case. If steam extraction from the turbine is employed, the transformities vary as a function of the power to heat ratio. Minimum transformities appear at full extraction, which corresponds to employment of a back-pressure turbine. This is the most emergy efficient way of coproduction since any steam condensation is avoided.

In the end main emergy contributors of biomass based coproduction were also discussed together with emergy indices.

1. Introduction

Heat and power are the major energy inputs for industry and the daily activities of life. Combined heat and power (CHP) generation has been considered as an important alternative to traditional power generation systems because of the significant energy saving and reduction of green house gases (GHG) emissions. In cogeneration systems, the energy efficiency is over 80% compared to ca. 35% in independent electricity generation (Onovwiona and Ugursal, 2006). About 50% more fuel is needed in the independent production for generating the same amounts of energy (Fig. 1). Yet the efficiency depends on the fuel and technology used.

The sustainability of energy production is essential. Emergy analysis is a method for environmental decision making from biosphere point of view (Odum, 1996). The method quantitatively illustrates not only energy aspects but also economic values and environmental factors. The emergy based environmental accounting represents all the required contributions of energy, services and materials to a final product and expresses them in the form of solar energy measured as solar emjoules (seJ), which is a quantity called emergy. Solar transformity is the unit to describe the solar energy required to create an energy unit of product (seJ/J). Therefore transformity is the inverse value of the system energy effectiveness. Emergy analyses are based on the amounts and transformities of inputs. Therefore their correct evaluation is important.

* Corresponding author.
E-mail addresses: markku.hurme@iki.fi, markku.hurme@aalto.fi (M. Hurme).
[1] Current address: Appraisal Center for Environment & Engineering, Beiyuan Street No.28 No.2 Building 305, Chaoyang District, Beijing 100012, China.

http://dx.doi.org/10.1016/j.ecoleng.2017.06.020
0925-8574/

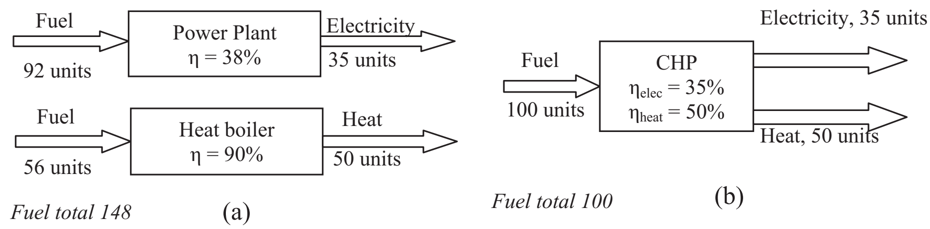

Fig. 1. An example of independent heat and power production (a) versus cogeneration (b) for production of the same energy amounts of heat and power.

2. Multi-product analysis

The application of emergy analysis to multi-product systems requires special care since the rules of emergy algebra need to be adhered. Because emergy is a footprint, it does not follow the rules of balance but the emergy algebra, which can be presented shortly as a set of *rules* (Brown and Herendeen, 1996):

1) The output of a unit equals to the inputs serially.
2) The emergy cannot be split for by-products; each by-product from a process or unit has the total emergy assigned to each pathway.
3) When a pathway splits, the emergy is assigned to each 'leg' of the split based on its percent of the total energy flow on the pathway.
4) Double counting is not allowed; Emergy in feedbacks may not be double counted. By-products when reunited cannot be added to equal a sum greater than the source emergy from which they were derived.

In multiproduct system emergy calculations the sum of emergies of the products is often larger than the sum of inputs. In case of *split streams* (rule 3) however, the emergy can be split based its energy content. In this case the products have the same composition since the stream was created by splitting (Fig. 2a).

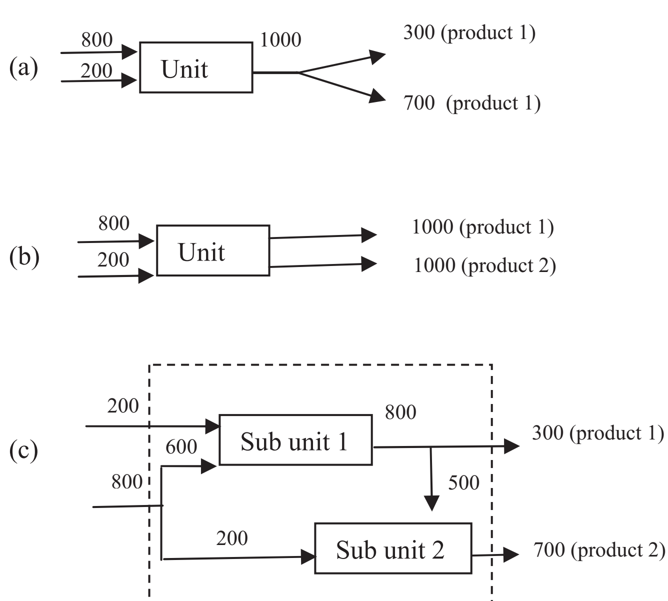

Fig. 2. Emergy counting of split streams (a), inseparable co-products (b) and semi-independent co-products (c).

2.1. Inseparable multiproduction

Realistic multiproduct cases can be complicated, which easily causes errors. Cao and Feng (2007) pointed out some easily made mistakes in emergy analysis of multi-product systems. To avoid errors, it is important first to distinguish the multiproduct category of system. *Inseparable multiproduct* systems are defined as systems, in which different products cannot be produced independently (and which are not split streams). It is wrong to apportion the whole input emergy between products in an inseparable multiproduct system because the emergy value is a memory of resources used in the processing. For inseparable products the emergies may not be split but each byproduct has the total emergy assigned to its pathway (see rule 2 and Fig. 2b).

Because the emergy analysis penalizes inseparable coproduction with respect to independent production, Bastianoni and Marchettini (2000) introduced a method of efficiency comparison using concepts joint transformity and the weighted average of transformities.

Joint transformity Tr_j is defined as the solar emergy required for the co-production divided by the sum of the energy contents of the products (Eq. (1)). The weighted average of transformities Tr_{ave} is calculated by dividing the sum of emergies of independently produced products by the sum of their quantities (Eq. (2)). Co-production is more efficient if the joint transformity Tr_j is smaller than the weighted average of transformities Tr_{ave}. This approach can show the relative efficiency of co-production vs. independent production but the transformities Tr_{ave} and Tr_j cannot be employed for other purposes.

The joint transformity in cogeneration Tr_j is defined:

$$Tr_j = \frac{EmE_{ec} + E_{sc}}{} \quad (1)$$

Em total emergy needed for cogeneration
E_{ec} energy of electricity produced in CHP
E_{sc} energy of steam produced in CHP
The average of transformities in independent production Tr_{ave} is:

$$Tr_{ave} = \frac{E_{ei}}{E_{ei} + E_{si}} Tr_e + \frac{E_{si}}{E_{ei} + E_{si}} Tr_s = \frac{Em_e + Em_s}{E_{ei} + E_{si}} \quad (2)$$

E_{ei} energy of electricity produced in independent production
E_{si} energy of steam produced in independent production
Em_e emergy of electricity produced in independent production
Em_s emergy of steam produced in independent production
Tr_e transformity of electricity
Tr_s transformity of steam

2.2. Semi-independent multiproduction

Semi-independent multiproduct systems are defined as systems in which products can be produced individually; i.e. a product can be produced without producing the other. These are typical e.g. in chemical production sites in which the product of one process can be used as a feedstock in the production of further products