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ON THE THERMOECONOMIC APPROACHES FOR FUEL AND WASTES ALLOCATION IN A COGENERATION PLANT: ARBITRARINESS AND COMPLEXITIES

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Abstract. *Thermoeconomic approaches connect Thermodynamics and Economics concepts, usually used for diagnosis, optimization and, mainly, cost allocation to the products of thermal plants. In the last years, the allocation of the overall fuel consumption and* CO_2 *emission have been gained importance, mainly to calculate the specific fuel consumption and the specific* CO_2 *emission due to the production of each intermediate and final products. Some methodologies use total exergy, some specific cases joined with the negentropy, to define the productive structure and other ones use disaggregated exergy. Bearing this in mind, this work aims at comparing different thermoeconomic approaches for fuel and waste allocation in a gas turbine cogeneration plant, in order to evaluate the arbitrariness and complexity involved. Although the involved complexity, the exergy disaggregation into enthalpic and entropic components (H&S Model) allows a systematic procedure for fuel and waste allocation. Thus, the chosen plant allows the treatment of dissipative component and waste, which are the main challenge of the thermoeconomic approaches. The methodologies utilized in this work are divided into three groups according to the kind of diagram used to represent the cost formation process (physical, productive and comprehensive), two thermoeconomics models (E and H&S Model), resulting in a total of six diagrams to obtain all the desired results.*

Keywords: *thermoeconomic approaches; cost allocation; wastes allocation; fuel allocation; disaggregated exergy*

1. INTRODUCTION

For complex energy systems, the use of conventional energy analysis techniques based on the First Law of Thermodynamics (mass and energy balance) to solve problems can be hard or not possible. Thus, Thermoeconomics can be considered a new science which, by connecting Thermodynamics and Economics, provides tools to solve these problems in complex energy systems. For example, a rational price assessment to the products of a plant based on physical criteria (Erlach *et al.* 1999)

Thermoeconomics has the purpose to combine in a single model, mathematically, Second Law Thermodynamic analysis with economic factors which one must consider in the design and/or performance evaluation and optimization of any energy system (von Spakovsky 1994).

Using the Second Law of Thermodynamics, diverse methodologies were proposed in the last 25 years, having in common the cost calculated on a rational basis (Serra *et al.* 2003). In agreement with (Lozano & Valero 1993a), the deeper and more detailed the disaggregation is, the clearer the interpretation of the obtained costs will be and the wider the catalog of applications to theoretical and practical problems.

The total exergy methodology is not able to properly handle with dissipative components without some arbitrariness. The solution is to merge with other productive equipment, but there is a loss of information about the cost formation process of these devices. Frangopoulos (1983) presented an elegant solution, which used total exergy with negentropy (E&S Model), nonetheless, the negentropy is a fictitious flow (Agudelo *et al.* 2012; Torres *et al.* 1996). This proposal allowed defining the fuel and product of the condensers. However, it has already been shown that this solution presents uncommon values of exergetic unit costs, i.e., lower than the unit (Agudelo *et al.* 2012; Santos *et al.* 2009a). In order to achieve consistent values of exergetic unit costs, Santos *et al.* (2006) approached the concept of negentropy with a different perspective. The authors proposed it as the entropic component to be used together with enthalpy, both considered as components of exergy (Lourenço *et al.* 2014). This Model already takes into account the dissipative component treatment and residue cost allocation automatically through its productive diagram without the uncommon values presented by the E&S proposal.

The methodologies can be based on physical, productive and comprehensive diagrams. In the comprehensive diagram (Avellar *et al.* 2018b, 2018a), both physical and productive internal flows are represented and their flows cost are assessed. Besides, the subsystems are connected using the same physical flows presented in the flowsheet of the plant, it reduces possible arbitrariness related to the subsystem interconnections (as already shown in (Avellar *et al.* 2018a; Modesto & Nebra 2006)), since there are no fictitious connectors, such as junctions and bifurcations used in productive diagrams.

The different thermoeconomic methodologies can provide, depending on the definition for product and fuels of each subsystem of the plant, different cost values. In the modelling of a gas thermal system, different thermodynamics models can be adopted, taking into account the working fluid, the combustion process and the associated irreversibility. (Santos *et al.* 2015)

The environmental study can be included in thermoeconomic models to calculate the environmental costs of the final products, such as specific CO_2 emission of each final product in cogeneration systems, which can be used as an indicator to quantify the environmental advantages of combined generation of heat and power in comparison with separated production of both products. (Santos *et al.* 2016).

Thus, this paper aims to present a comparison between different thermoeconomic methodologies, total exergy model and H&S model, for the allocation of waste and fuel to a cogeneration plant, evaluating the complexity and arbitrariness involved. The novelty of this work is to evaluate the advantages of having the subsystem component of the thermoeconomic diagram called environment for environmental charge allocation, such as the overall CO_2 emission.

2. COGENERATION PLANT MODELING

For the case studied of this present work, the flow sheet in Figure 1 was selected because it presents dissipative equipment and residues, which are points of discussion in the thermoeconomic analysis. The power cycle approached is a gas power generation plant that follows a Brayton cycle model with intercooling and using the residual heat in a Heat Recovery Steam Generator (HRSG) in order to utilize this residual energy to generate steam. The intercooler is the dissipative equipment to be analyzed and the exhaust gas leaving the HRSG represents the residues of the plant.

The thermodynamic states and their flows are exposed in table 1. To perform a thermodynamic modeling of the presented cycle, compressors and turbine operates with an isentropic efficiency of 86.27 and 89.74%, respectively (Dos Santos *et al.* 2015). The properties of the reference environment, chemical composition of the air, and thermodynamic properties of the fuel used in the combustion chamber were used based on the work of (Valero *et al.* 1994).

The analysis of the cycle covered in the paper addresses three working fluids, air (states 0 to 3), combustion gases (states 4 to 6), water (state a), steam (state b) and the fuel, methane (CH_4), presented in state "c". The composition of the exhaust gases leaving the combustion chamber was obtained by balancing the combustion reaction with an excess of air in order to control the outlet temperature of the combustion chamber and the following results were obtained: y_{CO_2} = 4.3%; y_{H_2O} = 10.38%; y_{O_2} = 11.15%; y_{N_2} = 74.16%. The chemical exergy of the exhaust gases was calculates according to the work of Valero et al., (1994) and it is shown in table 1.

To obtain the exergetic and energetic flows, a constant specific heat was used for states 0 to 3 ($c_{p_{air}} = 1.004\ kJ/kgK$) and another constant value for gases, from state 4 to 6 ($c_{p_{ex.gases}} = 1.17\ kJ/kgK$), as shown in the work by Araújo *et al.* (2020), and pressure drop of 5% for intercooler, combustion chamber and HSRG, according to Valero *et al.* (1994).

As the power plant reaches a steady state, the first and second compressors will consume 1,012 kW and 1,038 kW respectively. The turbine generates work in a rate of 5,052 kW to supply the compressors and generate electricity.

In order to obtain only positive values for the extensive properties, the reference was adjusted and, for this purpose, it was added an increment of 714.7 to all the thermodynamic state entropies (kW/K) and enthalpies (kW) values.

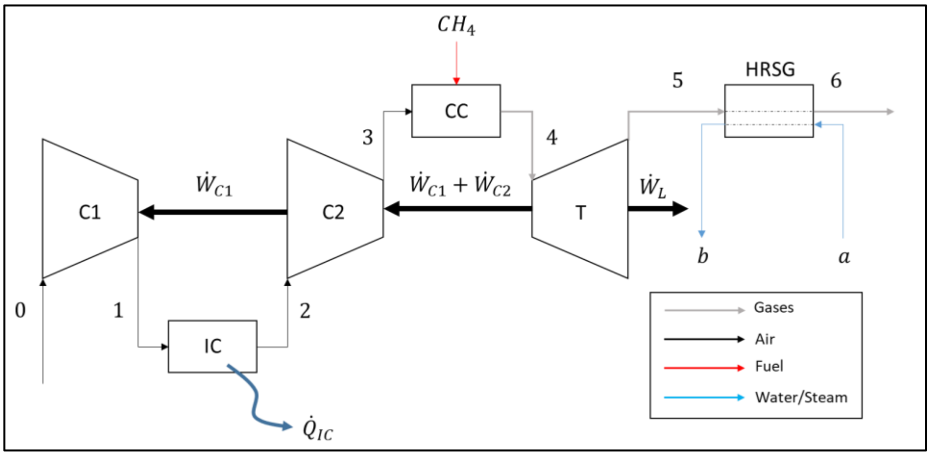

Figure 1. Brayton cycle with intercooler and heat recovery system's flow sheet

Table 1. Parameters of physical flows of the system.

States	Stream	Flow [kg/s]	T [ºC]	p [bar]	e [kJ/kg]	h [kJ/kg]	s [kJ/(kg.K)]	$x_{quí}$ [kJ/kg]
0	*air*	*10*	*25*	*1.013*	*0*	*71.5*	*71.5*	*0*
1	*air*	*10*	*126*	*2.48*	*91*	*172.7*	*82.0*	*0*
2	*air*	*10*	*26*	*2.356*	*72*	*72.3*	*0.1*	*0*
3	*air*	*10*	*127*	*5.768*	*166*	*173.8*	*10.6*	*0*
4	*gases*	*10.25*	*1,134*	*5.48*	*926*	*1,366.3*	*464.9*	*25*
5	*gases*	*10.25*	*712*	*1.066*	*416*	*873.7*	*482.3*	*25*
6	*gases*	*10.25*	*97*	*1.013*	*33*	*153.5*	*144.8*	*25*
a	*water*	*3.081*	*90*	*9*	*26*	*609.4*	*233.2*	*0*
b	*water*	*3.081*	*175*	*9*	*804*	*3,005.4*	*238.6*	*0*
c	*CH4*	*0.2504*	*25*	*1.013*	*51,850*			*51,850*

3. THERMOECONOMIC MODELLING

Thermoeconomic models applied for cost allocation describes the cost formation process by utilizing some thermodynamic magnitude to define the productive structure of the plant. The productive structure shows the productive purpose of the subsystems since it shows clearly its fuels and products in terms of physical or productive flows. Conventionally, the methodologies use physical or productive flows to show graphically the productive connection among the subsystems. Three types of diagrams are applied in this study: physical, productive and comprehensive diagrams. Physical diagram is a simplification of the flowsheet and uses physical flows only. The productive diagram uses productive flows only. Fictitious units (junctions and bifurcations) are used in the productive diagram to assist to drawing up the diagram. The comprehensive diagram use both physical and productive flows.

By definition of the productive structure, each subsystem is represented by means of a cost equation balance relating a thermodynamic magnitude and the unit cost of the internal flows and final products. The mathematical model lists a set of cost balance equations in each subsystem in order to calculate the unit costs. The unit cost of a flow (physical or productive) is the amount of resources some stream required to obtain one unit of this flow. In other words, it's a measure of efficiency of the production process associated to this flow (Valero *et al.* 2006). Thus, the exergetic unit cost (k, in kW/kW) is the amount of external fuel exergy required to obtain one unit of exergy of each flow of the plant diagram. Equation (1) gives the generic thermoeconomic cost balance for each subsystem of the diagrams.

$$\sum(k_{out} \cdot Y_{out}) - \sum(k_{in} \cdot Y_{in}) = k_f \cdot Q_f \qquad (1)$$

In Eq (1) k_{out} and k_{in} are the unknown variables representing the exergetic unit cost of the internal flows ate outlet and the inlet of each subsystem; Y_{out} and Y_{in} means the generic internal flows at inlet and outlet of each subsystem. The solution of the equation gives the exergetic unit costs of each internal flow and each final product. In this paper Y

assumes the thermodynamic magnitudes, such as mechanical power (W), total exergy (E), enthalpy (H) and negentropy (S), depends on the thermoeconomic model. Q_f is the external fuel exergy consumption (in kW) and k_f is the exergetic unit cost of the external fuel exergy. Since there is no exergy destruction before the formation process, k_f is assumed to be 1.00 kW/kW.

Each subsystem gives a single cost equation, thus auxiliary equations are necessary. At this point there are two different ways to obtain these last equations. Thermoeconomic models based on the productive diagram consider the equality criteria, where productive flows exiting the same productive unit must have the same unit cost. The models based on physical diagram, instead, adopt the fuel and the product principles. The fuel principle state that the cost of a given outlet flows is the same of an inlet flow if the flow is only used to produce a given product of the component. In other words, the unit cost is carried throughout the component without change the cost of the inlet flow. On the other hand the product principle considers that all the outlet flows defined as products of the components have the same unit cost.

In addition, the comprehensive thermoeconomic diagram can combine the main characteristics of both physical and productive diagrams. The first contributes with the connections using the same flows present in the flowsheet. The former allows the use of product and fuels of the subsystems presented in the diagram. Each subsystem acts as both component and productive unit, concepts introduced by physical and productive diagram, respectively. The comprehensive diagram shows at the same time the interrelation among the subsystems and their productive purpose for the entire plant.

For the mathematical modelling, the comprehensive diagram uses Eq. (1) to obtain the exergetic unit costs of the internal flows (physical and productive flows at same time), including the final products. Thus, each subsystem allows formulating two cost equations, one at the component boundary and other at the productive unit boundary. As well as in the physical and productive diagrams, auxiliary equation is required and both criteria can be used to solve the set of equations. Furthermore, the comprehensive diagram avoids the use of fictitious subsystems (junctions and bifurcations), which can be considered as an arbitrariness characteristic of the productive diagram.

For waste and fuel allocation, Eq. (1) must be modified into Eq. (2) and (3). Specific CO_2 emissions (λ, in kg/MWh) and specific CH_4 consumption (α, in kg/MWh) can be defined as the amount of emissions released, or fuel consumption, to obtain one unit of exergy of the given flow, respectively. In this case λ_f and α_f represents the amount of emissions generated and fuel consumption due to the combustion of one unit of the plant external fuel exergy, respectively.

$$\sum(\lambda_{out} \cdot Y_{out}) - \sum(\lambda_{in} \cdot Y_{in}) = \lambda_f \cdot Q_f \quad (2)$$

$$\sum(\alpha_{out} \cdot Y_{out}) - \sum(\alpha_{in} \cdot Y_{in}) = \alpha_f \cdot Q_f \quad (3)$$

The solution of the Eq. (2) and Eq. (3) returns the unknown variables specific CO_2 emissions (λ) and specific CH_4 consumption (α), respectively.

3.1 E Model

Using total exergy (E) as the magnitude to describe the cost formation process, the mathematical model of the cogeneration plant is represented by a set of equation obtained from cost balances of each subsystem. Table 2 shows the productive structure of each subsystem of the plant in terms of exergy for both physical and productive flows. The fuels and the products are defined as the decrease or increase in total exergy, respectively, external fuel consumption (Q_f), mechanical power (W) and useful heat (Q_u). As a component or productive unit, all subsystems have its products and fuels defined. However, the E Model is unable to clearly define the product to the dissipative equipment, intercooler (IC). Thus, the productive diagram based on E model not allows isolating the intercooler in the productive structure. As an alternative, the intercooler is arbitrarily merged to the low and high-pressure air compressors, forming a subsystem called CIC, in order to define its productive purpose. Furthermore, it is relevant to note that physical diagram treats the intercooler by the inlet and outlet flow (E1 and E2, respectively) but also does not allows thermoeconomic isolation.

Figure represents the physical diagram using total exergy magnitude. The subsystems are represented as components connected by the physical flows, in a similar layout of the plant flowsheet. The works (Frangopoulos 1994; Torres et al. 2008) agree that the cost of exergy from the waste and the resources used on its respective treatment methods must be distributed among the productive units, and thus to the final products, proportionally to its responsibility for such magnitude (Lozano & Valero 1993b). This proportionality is also known as residue cost distribution ratios and can be defined by different methods, i.e., there are no general criteria to define it. The SPECO and TCE methodologies allocated the residue in the combustion chamber (CC) since it was the equipment that originates de residue. Other methodologies, such as (Agudelo et al. 2012; de Faria et al. 2021; Seyyedi et al. 2010) distributes the residue among other equipment in a reasonable partition. For the sake of simplicity, this paper allocates the waste cost at the combustion chamber.

Table 2. Definitions of the fuels and the products using both physical and productive flows - E Model.

	System and Subsystems	Symbol	Fuel Physical	Fuel Productive	Product Physical	Product Productive	Residue
1	*Low pressure air compressor*	*C1*	W_{C1}	W_{C1}	E_1	$E_{1:0}$	
2	*Intercooler*	*IC*	E_1-E_2	$E_{1:2}$	-	-	Q_{IC}
3	*High pressure air compressor*	*C2*	W_{C2}	W_{C2}	E_3-E_2	$E_{3:2}$	
4	*Combustion chamber*	*CC*	Q_f	Q_f	E_4-E_3	$E_{4:3}$	
5	*Gas turbine*	*GT*	E_4-E_5	$E_{4:5}$	$W_L+W_{C1}+W_{C2}$	$W_L+W_{C1}+W_{C2}$	
6	*Heat recovery system generator*	*HRSG*	E_5-E_6	$E_{5:6}$	*Qu*	*Qu*	$E_6^{(1)}$
	Compressors and intercooler(2)	*CIC*	-	W_{CIC}	-	$E_{3:0}$	
	Cogeneration Plant	*CP*	Q_f	Q_f	$Qu+W_L$	$Qu+W_L$	

(1) the flue gas residue E6 is allocated at CC.
(2) CIC is defined to productive diagram.

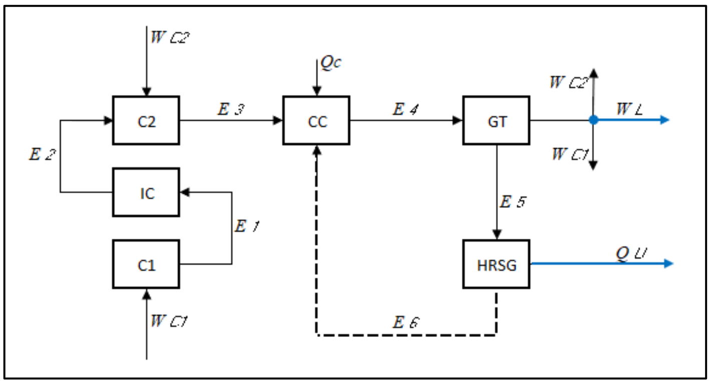

Figure 2. Physical diagram for the system using E model.

Figure 3 shows the productive diagram for the cogeneration plant based on E model. The fuels and the products are represented by productive flows ($E_{i:j}$) interconnected with the productive units (rectangles). The fictitious units (junction and bifurcation) receive all internal products of the plant and distributes for all productive units that has total exergy as fuel in the productive structure. The residue E_6 is implicitly allocated at heat recovery steam generator (HRSG) and gas turbine (GT) by the byproduct criteria. In addition, the CIC as productive unit has $E_{3:0}$ as product and W_{CIC} as fuel in the productive structure.

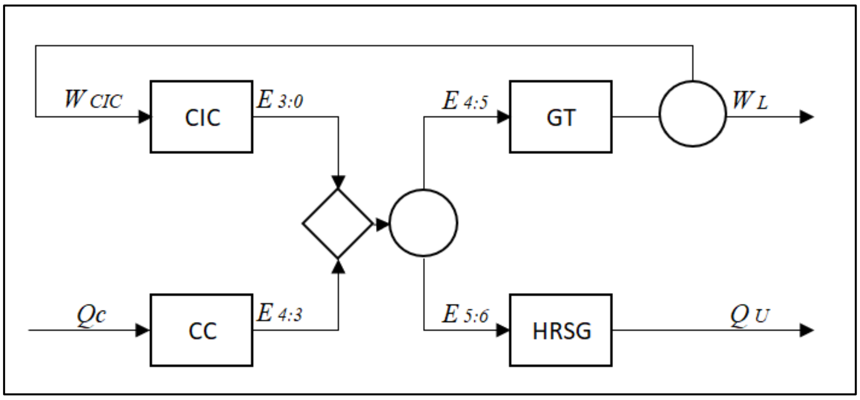

Figure 3. Productive diagram for the system using E model.

The comprehensive diagram for E model is shown in Figure . The subsystems acts as both productive unit (continuous line) and component (dotted line). The productive flows ($E_{i:j}$) are composed by physical flows (E_i) in an exergy loop. This kind of diagram allows intercooler only be represented as component since there is only a definition for outlet and inlet flows, nor a product. The cost of the flue gas residue E_6 as a physical flow is reallocated in the combustion chamber. The auxiliary equation for comprehensive diagram is based on the fuel principle that attributes the same unit costs for gas streams (E_3, E_4, E_5, E_6) and air streams (E_1 and E_2). The product principle attributes the same unit cost for mechanical power (W_L, W_{C1} and W_{C2}).

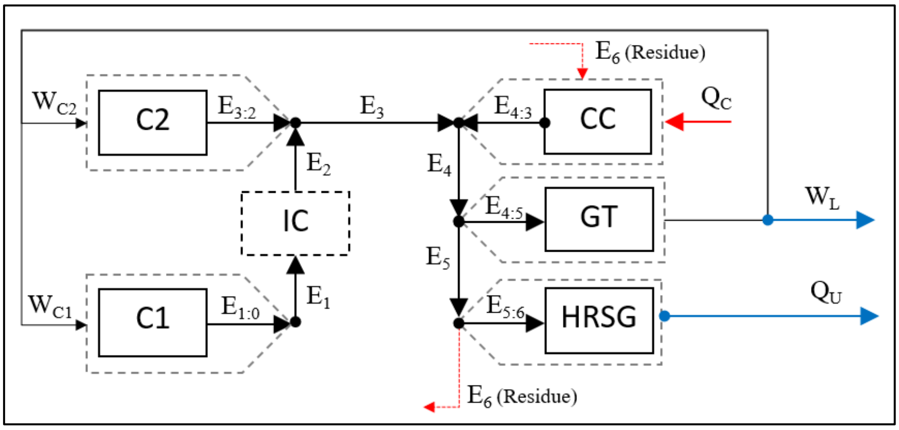

Figure 4. Comprehensive diagram for the system using E model.

3.2 H&S Model

The H&S model uses the physical exergy disaggregation in enthalpic (H) and entropic (S) components to define productive and physical flows of the cogeneration plant. Table 3 shows the productive structure for H&S model for each component of the system defining fuels and products by the use of enthalpy, entropy and chemical exergy. The H&S model was initially proposed by Santos *et al.(* 2009b) using the productive diagram. Thus this paper applies cost allocation, waste and fuel allocation for productive and comprehensive diagram. Additionally, the H&S model improves the accuracy of the results in the thermoeconomic analyses by disaggregating the physical exergy. Nonetheless, there is an increase of complexity.

First, it is important to note that H&S model allows a thermoeconomic isolation for dissipative component, such as an intercooler (IC), since it defines its product in terms of entropic term for both physical (S_1-S_2) and productive flows ($S_{1:2}$). Thus, the productive diagram represented in Figure 5 shows graphically and clearly the isolation of intercooler from the compressors C1 and C2, different from E model.

The productive diagram uses the productive flows and fictitious units (junctions and bifurcations) to connect the subsystems, thus allowing the cost evaluation of the internal productive flows and the final products (Erlach et al. 1999; Pablo Arena & Borchiellini 1999). The presence of fictitious units can lead to arbitrariness as it is up to the analyst to define the cost formation process (Valero et al. 2006).

For the waste cost treatment, the H&S model uses the environment (ENV) as productive unit to allocate the existing waste, thus making the cost allocation of waste explicitly. In addition, the environment is only responsible for redistributing the entropic term to productive units that increase the working fluid entropy. Besides, the environment is responsible to dissipate chemical exergy caused by the combustion chamber ($Ch_{4:3}$).

The mathematical model for H&S productive diagram allows one cost equation for each seven productive unit presented in Figure 5. Multiproduct is the method used to formulate the auxiliary equation in each bifurcation.

Table 3. Definitions of the fuels and the products using both physical and productive flows – H&S Model.

			Fuel		**Product**		
	System and Subsystems	**Symbol**	**Physical**	**Productive**	**Physical**	**Productive**	**Waste**
1	*Low pressure air compressor*	*C1*	$W_{C1}+S_1-S_0$	$W_{C1}+S_{1:0}$	$H_1- H_0$	$H_{1:0}$	
2	*Intercooler*	*IC*	H_1-H_2	$H_{1:2}$	S_1-S_2	$S_{1:2}$	
3	*High pressure air compressor*	*C2*	$W_{C2}+S_3-S_2$	$W_{C2}+S_{3:2}$	$H3-H_2$	$H_{3:2}$	
4	*Combustion chamber*	*CC*	$Q_C+S_4-S_3$	$Q_C+S_{4:3}$	$H_4-H_3+Ch_4-Ch_3$	$H_{4:3} + Ch_{4:3}$	
5	*Gas turbine*	*GT*	$(S_5-S_4)+(H_4-H_5)$	$S_{5:4}+H_{4:5}$	$W_L+W_{C1}+W_{C2}$	$W_L+W_{C1}+W_{C2}$	
6	*Heat recovery steam generator*	*HRSG*	H_5-H_6	$H_{5:6}$	$Q_U+S_5-S_6$	$Q_U+S_{5:6}$	E_6
7	*Environment*	*ENV*	H_6-H_0	$H_{6:0}$	S_6-S_0	$S_{6:0}$	
	Cogeneration Plant	*CP*	Q_C	Q_C	Q_U+W_L	Q_U+W_L	

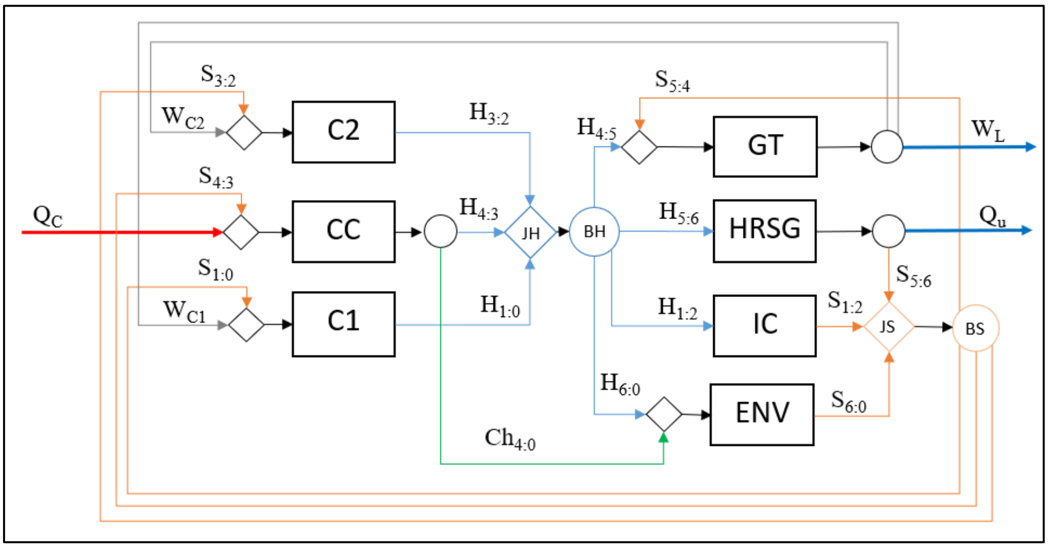

Figure 5. Productive diagram for the system using H&S model.

The comprehensive diagram for H&S model is represented in Figure 66. The intercooler is isolated and acts as both productive unit and component trough the definition of fuel and product in terms of enthalpy and entropic components. The subsystems are interconnected by physical flows composed of both enthalpy and entropic terms, in a loop arrangement. Besides, chemical exergy presents a loop too however only the combustion chamber (CC) and environment (ENV) are interconnected since only this equipment present chemical exergy variation. In this paper, the waste cost is allocated at combustion chamber (whereas this equipment originates the flow, according to TCE and SPECO) and the environment. It is important to note this system has three subsystems that's contributes to produce the entropic term for the plant: intercooler (IC), steam generator (HRSG) and environment (ENV). On the other hand, only compressors (C1 and C2) and combustion chamber increase the enthalpy of the working fluid.

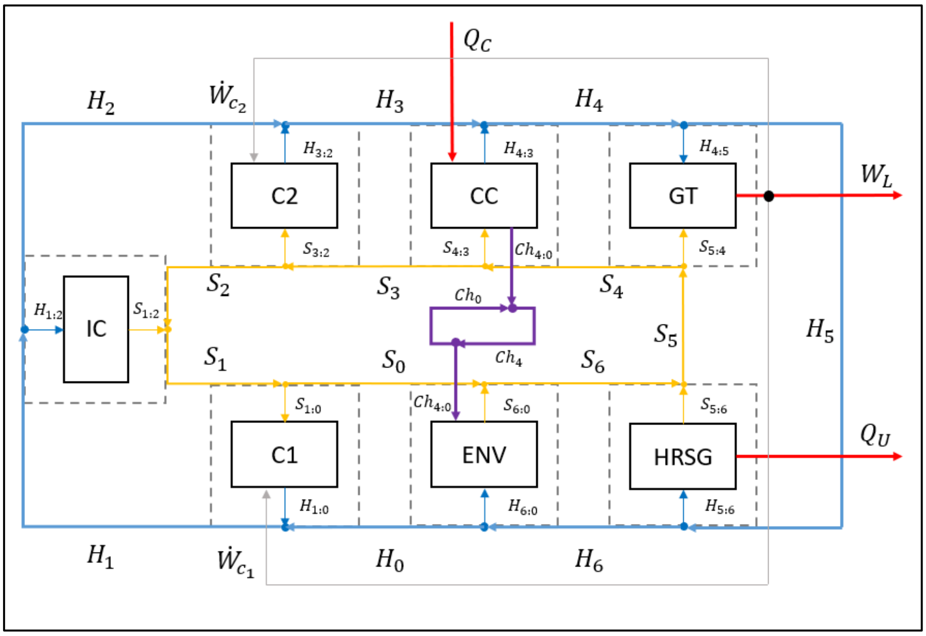

Figure 6. Comprehensive diagram for the system using H&S model.

4. RESULTS AND DISCUSSIONS

This paper applied a thermoeconomic analysis in a cogeneration plant using E model and H&S model with physical, productive and comprehensive diagrams. The cost allocation method was evaluated to assess exergetic unit costs (kW/kW), specific CO_2 emissions (kg/MWh) and CH_4 consumption (kg/MWh).

By the E model, all thermoeconomic diagrams were represented. The waste residue (E_6) was arbitrarily allocated in the combustion chamber (CC) at physical and comprehensive diagrams. In the productive diagram the residue was implicit allocated whereas the fictitious components distribute its cost for equipment that increases the exergy of the system, GT and HRSG, here in. Furthermore, the productive diagram not allowed a thermoeconomic isolation of the dissipative component, intercooler (IC) since it was not possible to define productive purpose of this subsystem and a new productive unit CIC was necessary. Here in, the IC was arbitrarily joined to compressors but could be allocated in another unit, depends on the analyst interpretation. The comprehensive diagram, by considering the subsystems as both productive unit and component, deals with IC trough physical flows and not isolate it. Thus, despite the less complexity, the E model were not capable to deal with waste cost allocation and dissipative components without arise some level of arbitrariness.

Considering H&S Model, final products costs were obtained for productive and comprehensive diagrams only. Since this model considers the environment as a subsystem for the productive structure definition, where the waste residue was allocated. In the comprehensive diagram the residue (thermal and chemical contents) was explicitly allocated on the subsystem ENV while in the productive diagram, implicitly, throughout entropic component and distributed for equipments that consumes entropic flow. Additionally, for both diagrams the dissipative component IC was isolated trough enthalpic and entropic components which allows visualize the cost formation process for IC as both component and productive unit ate same time. For the specific CO_2 allocation, the comprehensive H&S model allows the allocation both in combustion chamber as environment.

Table 4 shows the unit costs for the final products (mechanical power and useful heat) for the models applied in this paper. The results confirm that no matter of the diagram, when the same treatment was dispensed to allocate the residues costs the final costs are the same. All three allocation criterion studied in this paper achieves the same results for the final products considering E Model. For H&S Model, the same behavior occurs comparing the final products, with a slight difference as showed. For specific CO_2 emissions the allocation occurs as both in CC and ENV. The last one results in final products cost of 494.8 kg/MWh and 426.8 kg/MWh for useful heat and mechanical power, respectively. It indicates a decrease and a rise of 2.21% and 2.11%, respectively comparing to the CC allocation.

The results also highlight a distinct behavior between the E and H&S thermoeconomic model, i.e., the E Model overloads the exergetic unit cost of heat by 13.7%, while the H&S Model, the power, by 15.09%. Same percentages variation occurs in the specifics CO_2 emission and CH_4 consumption. This is explained by the dissipative equipment isolation in the H&S Model, as well as by the different waste allocation procedures for each thermoeconomic model.

Table 4. Exergetic unit cost, specific CO_2 emissions and specific CH_4 consumption of useful heat and mechanical power – E and H&S models.

	Exergetic Unit Cost (kW/kW)		***Specific CO_2 Emissions (kg/MWh)***		***Specific CH_4 Consumption (kg/MWh)***	
	Useful Heat	***Mechanical Power***	***Useful Heat***	***Mechanical Power***	***Useful Heat***	***Mechanical Power***
E Model - Physical Diagram	3.012	1.902	575.2	363.3	209.1	132.1
E Model - Productive Diagram	3.012	1.902	575.2	363.3	209.1	132.1
E Model - Comprehensive Diagram	3.012	1.902	575.2	363.3	209.1	132.1
H&S Model - Productive Diagram	2.649	2.189	505.8	418.2	183.9	152.0
H&S Model - Comprehensive Diagram(1)	2.648	2.190	506.0	418.0	183.9	152.0
H&S Model - Comprehensive Diagram(2)			494.8	426.8		

(1) CO_2 allocation at CC
(2) CO_2 allocation at ENV

5. FINAL REMARKS

This paper contributes for thermoeconomics discussion by the analysis of the cost formation process through three thermoeconomic diagrams considering waste and fuel allocation. The plant was chosen due to the presence of a dissipative component, intercooler, and the exhausting gases waste in order to verify the arbitrariness and complexities involved in the thermoeocnomic modeling regarding these points.

Besides handle less complexity in the thermoeconomic modeling, the E Model could not isolate the dissipative component and the treatment for its allocation requires the analyst's interpretation. This procedure highlights the arbitrariness to deals with dissipative components and it is more evident in the productive diagram since different productive structure can be formulating with the intercooler. On the other hand, the flue gas cost was arbitrarily allocated at CC in both physical and productive diagram while implicitly allocated in HRSG. This former procedure doesn't allow visualizing the waste cost formation separately.

H&S Model showed to be able to overcome this arbitrariness in both dissipative component and waste cost allocation since it uses enthalpic and entropic components to define the productive structure of intercooler and, systematically, introduces the environment in the modeling. Thus, the arbitrariness is intrinsically related with the productive diagram. On the other hand, the H&S Model increases the complexity of the modeling due to the exergy disaggregation and it was more evident in the comprehensive diagram. This last, however, allows calculate both physical and productive flows costs and the former flows is used to perform the interconnection between subsystems, avoiding, this way, the arbitrariness due to the use of fictitious equipment presents in the productive diagram.

The importance of choosing the suitable diagram and an adequate disaggregation exergy model for cost formation process definition was also highlighted in this study. The diagram and the model are generaly associated to the analyst's interference in the thermoeconomic modeling. Thus, a systematic cost formation process is important to enhance and consolidate the thermoeconomic discussion around the arbitrariness and complexities related to cogeneration plants.

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