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Assessment of Environmental Impacts of Tar Releases from a Biomass Gasifier Power Plant for Decentralized Electricity Generation

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Abstract

Biomass gasification systems may be relevant for decentralized power generation from recoverable agricultural and wood residues available in rural areas. Although they have many positive effects, these systems can also affect environment and human health. Indeed, during the process of biomass gasification, tars are produced and generally discharged in the local environment. This work deals with the analysis of the environmental impacts of a biomass gasifier power plant project. It compares the impacts of tar releases from the conversion of two biomasses: cotton stalks and rice husks, and that of two disposal modes (into water or on soil). The gate-to-gate environmental impacts are assessed through Life Cycle Assessment (LCA) approach. The results of this study indicate that the environmental impacts of electricity production from cotton stalks are higher than that of from rice husks. Results also show that the impact levels are high when tars are dumped into water comparatively to their discharge on soil. For environmental research, these results represent a significant step of a global environmental assessment of the studied systems.

Keywords: Biomass gasification; environmental impacts; Life Cycle Analysis (LCA); tars.

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1. Introduction

Biomass gasification is one of effective technologies for decentralized electricity generation from agricultural and wood residues. The deployment of biomass gasifier power plant has demonstrated to be relevant in terms of efficiency, growth of local energy services and economy through jobs creation [1], [2] . However, although having these positive effects, they can also affect environment and human health.

Nomenclature

CTUe	Comparative Toxic Unit for ecosystems	HTC	Human toxicity carcinogenic effects (CTUh)
CTUh	Comparative Toxic Unit for humans	IF_{eq}	Equivalent impact factor
EI_i	Environmental impact (impact unit/kWh)	LCA	Life Cycle Assessment
Em_{tar}	Total emission of tar (kg/kWh)	m_{tar}	Specific emission of tar (kg/Nm^3)
FWE	Freshwater ecotoxicity (CTUe)	Nm^3	Normal cubic meter
GHG	Greenhouse gas	V_{gas}	Specific consumption of syngas (Nm^3/kWh)
HTNC	Human toxicity non carcinogenic (CTUh)		

Biomass gasification is a thermo-chemical conversion in a low oxygen environment, producing syngas. The syngas is mainly made of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), nitrogen (N_2) and other hydrocarbons as well as impurities including particulate matters, and tars. Tars content in an air blown downdraft fixed bed biomass gasifier (one of gasification technologies) is usually in the range of 0.01 to 6 g/Nm^3. However, they must be removed until 0.1g/Nm^3 before the syngas can fed an internal combustion engine generator to produce the electricity [3].

When tars are separated from syngas and collected, they are generally discharged in the local environment sometimes without any treatment [4]. They represent a danger to the environment, and the health due to the presence of chemical substances known to be “carcinogenic, mutagenic, and/or toxic’’. Hence, to improve the feasibility and durability of biomass gasification, its environmental performance should be investigated to reduce the socio-environmental effects.

Various methodologies have been applied for examination of environmental impacts, while Life Cycle Assessment (LCA) is one of the most widely used methods. In the most of the studies, the researchers [5]–[7] have focused on GHG emissions, acidification potential, eutrophication potential to assess the environmental impacts of different plant sizes or feedstock types for power or heat generation from biomass gasification. Very few paid attention to the environmental impact categories related to tar emissions.

This study aims to analyze the environmental impacts related to the tar releases from a biomass gasifier power plant project for electricity supplying of an isolated rural area. Using the LCA approach, it compares the impacts of the power generation from the cotton stalk and rice husk; and two scenarios of disposal corresponding to discharge into the water (river) or on the soil.

2. Methodology

2.1 Life cycle assessment framework

Life cycle Assessment (LCA) is a cradle-to-grave approach formalized by the International Organization for Standardization [8], which has been regarded as a valuable environmental assessment tool for the chemical industries. Generally, a LCA study is carried out in four phases: goal and scope definition, life cycle inventory, impact assessment, interpretation.

Goal and scope definition: The production system considered in this study is subdivided into two processes: the reception and the preparation of dry biomass on the power plant site, and the process of conversion of biomass into electricity. So, the biomass logistic chain and electricity distribution network are out of the scope of the study. The main objective of this LCA is to analyze the environmental impacts especially related to the releases of tars resulting from the biomass process conversion. Hence, for this LCA, the « gate-to- gate » scheme is used. Since the primary function of the system is to produce electricity, the impacts were evaluated on the basis of a functional unit of 1 kWh of electricity generated.

*Life cycle inventory***:** In accordance with the purposes of our study and system boundary, the amount of tar produced per kWh of electricity generated is first determined. Then, the chemical substances present are inventoried**.** Using the following expression, the quantity of tar is calculated:

$$Em_{tar} = V_{gas}.m_{tar} \tag{1}$$

Note that the quantity (Em_{tar}) of tar generated depends on power plant performance. Thus, the volume (V_{gas}) of syngas consumed to produce 1 kWh of electricity is estimated from a thermodynamic model developed under Matlab. The assumptions concerning the specific emissions of tars (m_{tar}) and the inventory of the chemical substances were adapted from literature data [9] for the rice husks and expertise data from’’Centre International de Recherche Agronomique pour le Développement (CIRAD)’’ for the cotton stalks. Thirty two (32) chemical substances are identified for the rice husks and 38 for the cotton stalks.

Impact assessment: The impacts per kg of tar (equivalent impact factor) was evaluated using the impact factor of each chemical substance proposed by ILCD 2011 Midpoint + (V.1.08) method in SIMAPRO tool [10]. It was chosen because it covers the greatest number of major chemical substances contained in the tars. The environmental impacts considered are: *human toxicity carcinogenic effects* (HTC), *human toxicity non carcinogenic effects* (HTNC), *freshwater ecotoxicity* (FWE). Finally, the environmental indicators (EI_i) for the entire process were calculated using the equivalent impact factor (IF_{eq}) by the following formula:

$$EI_i = \sum IF_{eq}.Em_{tar} \tag{2}$$

2.2 Implementation and input data

The approach described above is applied to a biomass gasifier power plant project for electricity supplying of a village (Badara) in the South-west of Burkina Faso, West-Africa. Based on forecast load profile data available, the total daily energy need for the village has been estimated to about 965 kWh with a maximum power peak load of 75 kW including 10% online loss of distribution network [11]. To fulfill the electrical demand of selected village, the production system capacity is set at 100 kWe, assuming a maximum power of 15 kWe of the auxiliaries and 90% maximum operating load. Rice husks and cotton stalks are the biomass feedstock available in the study area [12]. For a proper functioning of the gasification systems, it is advisable to operate with sufficiently dry biomass. In the case of agricultural residues, the moisture content is usually low compared to forest woods. The moisture content of cotton stalks is assumed to be 15 % and 12 % for rice husks.

As previously mentioned, the assumptions concerning the specific emissions of tars and the inventory of the chemical substances were adapted from literature and expertise data on downdraft gasifier. Since the data on tars from cotton stalks are limited, they have been assimilated to wood by using data from ‘’Centre International de Recherche Agronomique pour le Développement (CIRAD). The tar concentration in the syngas was evaluated at 1.75 g/Nm^3 on average by a quantitative estimation method. Thirty eight (38) key chemical substances are identified. For the rice husks, the data collected on an Imbert downdraft gasifier have been used. Tar concentration was determined by semi-quantitative method and evaluated at 1.72 g/Nm^3 on average. Thirty two (32) key chemical substances are indicated [9].

It should be noted that many substances are common to tars from both biomass (cotton stalk and rice husk) such as Phenol, Naphthalene, Cresol, Fulfural; but they are present in different proportions. Nevertheless, other specific substances are identified as the Quinoline in the tars from cotton stalks; the Cathecol in the tars from rice husks. It is assume that all the quantity of tar produced is collected and rejected in the environment.

3. Results and discussion

First, this section discusses the results of the assessment of environmental impacts of the electricity generation from the two biomass and the two discharge modes (either into water or on soil), and then highlights the major contributors to the impacts.

3.1. Environmental impacts of biomass gasifier power plant

Fig. 1-3 present for each environmental indicator, the impact levels for the two considered biomasses and the two disposal mode. Regardless of the environment compartment, it can be observed for the human toxicity non carcinogenic (Fig. 1) that the impact levels of the tars from cotton stalks are higher than those from the rice husks. In the case of the human toxicity carcinogenic (Fig. 2) the observed trend is the same. While in the case of the freshwater ecotoxicity (Fig.3), the impact levels for the two biomasses are similar. The comparison of the impact levels between the two compartments of environment for each biomass shows that the risk of negative effects is higher in case of the discharge into water than on soil for all impact categories. Indeed, the impact of human toxicity non carcinogenic is 10 times higher into water than on the soil for the tars from cotton stalks, and 50 times for the tars from the rice husks. Considering the human toxicity carcinogenic, the impact is 20 times higher in water than on soil for cotton stalks and 85 times for the tars from the rice husks. With regard of the freshwater ecotoxicity, the variability of impact levels between the water and the soil is very high. It is 65 times for the tars from the cotton stalks and 95 times in the case of tars from the rice husks.

These results can be explained by (i) the presence of some specific chemical substances in the tars of each biomass, (ii) a different proportion of the common chemical substances, and (iii) the variability of behavior of the chemical substances in each compartment (water or soil).

3.2. Major contributors to environmental impacts

The contributions of the chemical substances to the impact of human toxicity non carcinogenic are presented in the Fig. 4 and 5 for the cotton stalks and the rice husks respectively. The results demonstrate that the chemical substances of tars vary from one biomass to another. In addition, for a same biomass, the chemical substances which contribute to impacts vary from one environmental compartment to another. For the cotton stalks, the contribution of Naphthalene is estimated to about 55 % at the soil level while its contribution is of 44 % at the water level followed by Formaldehyde (24 %). For the case of rice husk, the predominant contributors are Fluoranthene (57 %) and Cyclohexane (25 %) at the soil level. Pyridine and Fulfural are the most influential substances into water with 42 % and 32 % respectively.

Concerning the impact of human toxicity carcinogenic, the results show again for the cotton stalks, the predominance of Naphtalène (62% of the effect) at the soil level followed by Benzofuran (26 %). While into the water, Formaldehyde (49 %) is the most important contributor followed by Naphthalene (39 %). For the tars from rice husks, Catechol (100 %) is responsible for 100 % of the effect at the soil compartment. However, into water, its contribution is estimated at 40 % and Naphtlene contribute at 34 %.

Regarding the freshwater ecotoxicity, the contribution of Naphthalene is again predominant at the soil compartment for the tar from cotton stalks and estimated at 43 %. It is followed by Anthracene which the contribution is estimated at 23 %. At water compartment, in addition to Naphtalene, the contributions of Phenol 3-4 dimethyl- and Formaldehyde are also very high (37 %, 28 % and 17 % respectively). However, for the tars from the rice husks, Acetic acid has contributed to 70 % followed by Catechol (20 %) at the soil compartment. Anthracene and Fluoranthene have contributed to 44% and 27 % respectively at water level.

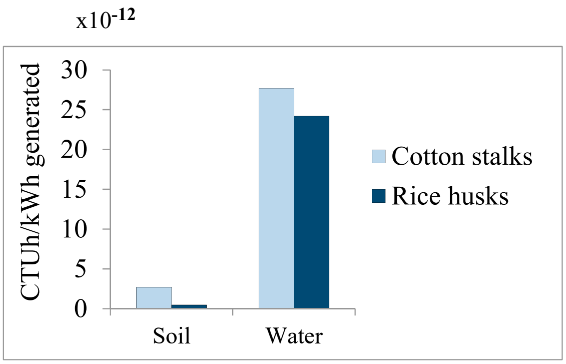

Fig. 1: Environmental impacts: Human toxicity non carcinogenic (CTUh/kWh)

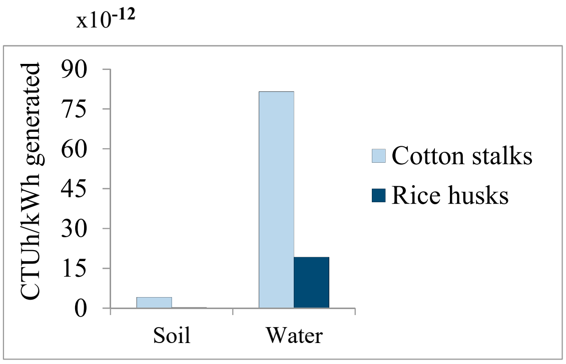

Fig. 2: Environmental impact: Human toxicity carcinogenic (CTUh/kWh)

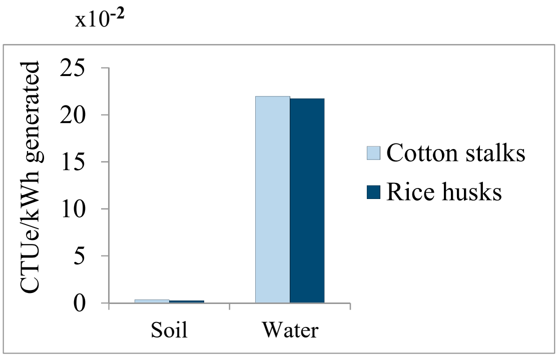

Fig. 3: Environmental impact: Freshwater ecotoxicity (CTUe/kWh).

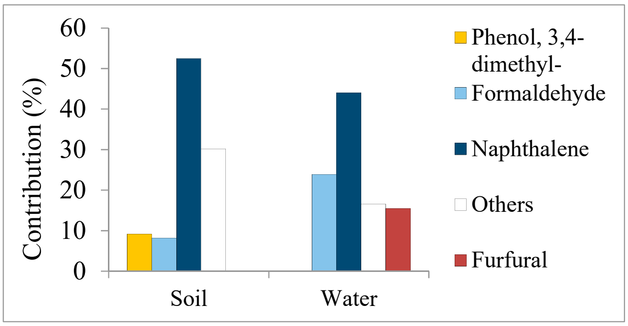

Fig. 4: Major contributors to human toxicity non carcinogenic for the cotton stalks.

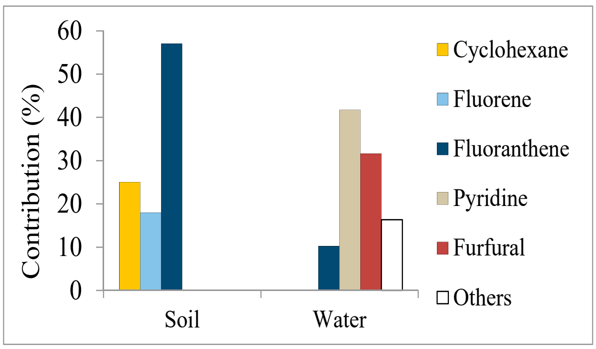

Fig. 5: Major contributors to human toxicity non carcinogenic for the rice husks.

4. Conclusion

This paper analyzes the environmental impacts of a biomass gasifier power plant project for electricity supplying of an isolated rural area. It compares the impacts related to the releases of tar from the conversion of cotton stalks and rice husks. Based on Life Cycle Assessment through ILCD 2011 Midpoint + (V.1.08) method, the environmental impacts are assessed in terms of human toxicity no carcinogenic effect, human toxicity carcinogenic effect and freshwater ecotoxicity. Our study shows that power generation from rice husk is better for environment than from cotton stalks. The toxicity is far higher for discharge into water than for discharge on soil. The toxicity is far higher for discharge into water than for discharge on soil. The most important substances contributing to the impacts of the discharge in water are: Naphthalene, Formaldehyde, Phenol in the case of cotton stalk and Pyridine, Fulfural, Anthracene in the case of rice husk. However, it should be noted that, most existing assessment methods, do not or only partially take into account the impacts of chemical substances discharge on soil. For environmental research, these results represent a significant step of a global environmental assessment of a biomass gasifier power plant. Furthermore, the results could be used to reduce the impacts of the numerous running gasification systems all over the world.

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