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Life cycle assessment of rice straw utilization practices in India

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HIGHLIGHTS

- A comparative LCA of Rice straw utilization practices in India.
- Four scenarios studied were use as, fertilizer, fodder, electricity and biogas.
- Scope of the study starts from collection of straw to the end use of the products.
- System expansion is used for accounting emissions from the replaced product.
- Electricity and biogas give highest benefits in most of the environmental impacts.

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ABSTRACT

The aim of this study is to find potential utilization practice of rice straw in India from an environmental perspective. Life cycle assessment (LCA) is conducted for four most realistic utilization practices of straw including: (1) incorporation into the field as fertilizer (2) animal fodder (3) electricity (4) biogas. The results show that processing of 1 ton straw to electricity and biogas resulted in net reduction of 1471 and 1023 kg CO_2 eq., 15.0 and 3.4 kg SO_2 eq. and 6.7 and 7.1 kg C_2H_6 eq. emissions in global warming, acidification and photochemical oxidation creation potential respectively. Electricity production from straw replaces the coal based electricity and resulted in benefits in most of the environmental impacts whereas use as an animal fodder resulted in eutrophication benefits. The burning of straw is a harmful practice of managing straw in India which can be avoided by utilizing straw for bioenergy.

1. Introduction

India is an agro-economic country with 13.7% (GoI, 2013) share of agriculture in gross domestic product (GDP). The majority of land is used for farming and a wide range of crops are cultivated in the different regions. The major annual crop production is rice (104 Mt) followed by wheat (93 Mt). In 2013, the world rice production was 477 Mt, wherein, China was the first producer with 144 Mt and India, second with 104 Mt (21% of total world rice production) (AIREA, 2014). Consequently, rice straw alone is produced in large quantities and contributes to 23% of the total agricultural crop residue (IARI, 2012). In most states of India, farmers grow three crops in a year and the mode of harvesting is changing from manual to mechanical, which leaves the straw standing in the fields. To clear the field for the next crop farmers apply the illegal practice of burning of straw leading to harmful effects on the environment and leads to the loss of nutrients such as N, P, K, and S (Gadde et al., 2009b). One ton of rice straw on burning in the field is estimated to produce, on average (kg) of 1168 CO_2, 1.0 CH_4, 0.06 N_2O, 27.8 CO, 3.2 nonmethane hydrocarbon (NMHC), 2.9 NOx, 1.6 SO_2 and 10.4 total particulate matter (TPM) emissions (Gadde et al., 2009b; Silalertruksa and Gheewala, 2013; Venkataraman et al., 2006). The biomass managed predominantly through burning leads to significant air pollution and has now been banned across the country. Furthermore, nutrients accumulation get localized to the area where straw is burnt and depletion in rest of the field (Escribà and Porcar, 2010). Therefore, to avoid the deleterious effects of burning and to take advantage of the huge energy potential of straw, the utilization of straw for various other activities should be promoted (Gadde et al., 2009a).

There are several productive techniques that can be used for straw management such as composting (Escribà and Porcar, 2010), recycling in soil (Gadde et al., 2009a; Bhattacharyya et al.,

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2012), production of electricity (Suramaythangkoor and Gheewala, 2011; Shafie et al., 2014), animal fodder (Gadde et al., 2009a; IARI, 2012). In addition, rice straw is also a promising feedstock for ethanol and biogas production (Börjesson and Berglund, 2007; Jana and De, 2016; Singh et al., 2014; Spatari et al., 2010). The management of rice straw has agricultural and environmental implications particularly related to greenhouse gas (GHG) emission and energy use (Escribà and Porcar, 2010). By adopting these management practices, burning can be avoided that could reduce harmful emissions significantly. Since, the practice of utilizing rice straw is limited and varies state wise; therefore, the surplus amount of rice straw availability in India also varies as presented in Table 1.

Life cycle assessment (LCA) studies are reported highlighting the management and utilization of rice straw in different countries such as, fertilizer in India (Bhattacharyya et al., 2012; Pandey et al., 2012) fuel and fertilizer in Thailand (Silalertruksa and Gheewala, 2013), ethanol production (Soam et al., 2016), electricity production in Malaysia (Shafie et al., 2014) and China (Liu et al., 2011). Several LCA studies have been reported in Thailand for use of rice straw for dimethyl ether (DME) production (Lecksiwilai et al., 2016; Silalertruksa et al., 2013), heat and power (Delivand et al., 2012; Suramaythangkoor and Gheewala, 2011). In Philippines, a study was conducted where authors identified that early incorporation of straw in soil is most cost effective and environment friendly practice (Launio et al., 2016).

India is suffering from the acute problem of rice straw burning and its management has become a serious issue (Indian Express, 2016). Therefore, a comparative study is essential to analyze different rice straw practices from an environmental perspective. The study aims to fill the current gap in straw management by evaluating and comparing the environmental performance of four rice straw utilization practices that include: (1) straw incorporated into the field as fertilizer (2) use as animal fodder (3) use for electricity production and (4) use for biogas production. This is the first study, wherein four different scenarios covering most realistic utilization practices based on practical and technical perspective are analyzed. In addition, the above mentioned literature studies only considered energy analysis and GHG emissions reduction. The other important environmental impact categories like eutrophication, acidification, and photochemical oxidation potential for different practices have not been considered in the above literature. The results of study will help to find out the environmental performance of different rice straw utilization practices. The results would assist government and policy makers in identifying, recommending and investing in sustainable utilization technology for rice straw management in India.

2. Methodology

LCA is an assessment tool which is used to quantify and evaluate the environmental impacts of and product, process and service. This tool has been widely used to evaluate environmental assessment of bioenergy systems (Cherubini and Stromann, 2011; Gnansounou et al., 2015; Soam et al., 2015) and used in current study to evaluate environmental performance of straw utilization practices. The ISO standards 14040/44 (ISO, 2006a,b) were followed while conducting the LCA and accordingly methodology is divided in following sections.

2.1. Goal and scope

LCA is conducted for the four rice straw utilization practice in India with an aim to identify the best practice from an environmental perspective. Processing of 1 ton dry rice straw is the reference flow which gives different functions in four scenarios. Since, the function delivered by four scenarios are different i.e. first scenario serve the purpose of fertilizer, second as fodder, third and fourth scenario as bioenergy. Hence, comparison of results are based on processing of 1 ton straw as it is not possible to designate a single functional unit in the study.

The system boundary of the rice straw utilization systems is shown in Fig. 1. Based on the data availability the geographical boundary selected are Punjab and Uttar Pradesh, two major rice producing states of northern India. The system boundary starts with the rice straw collection and environmental impacts from cultivation phase are not considered. This is in accordance with ISO standards (ISO, 2006a,b) and RED (Renewable Energy Directive) (RED, 2009) methodology which states that waste agricultural crop residues such as rice straw should be considered to have zero life cycle emissions up to the point of collection. In systems, wherein rice straw is removed from the field, the process includes collection of straw, bailing, transport, production and end use of the product. The system expansion approach was adopted to consider the emissions from the substituted product.

The emissions from infrastructure and capital investment are not considered in the study. The biogenic CO_2 emissions from combustion or burning or decomposition of straw are not included. Impacts of land use changes are not addressed since we have analyzed the systems for already available surplus rice straw. Land has not been diverted for straw production and therefore land use changes are out of scope in current study.

2.2. Scenarios description and life cycle inventory (LCI)

The average yield of rice in the northern India is 3.5 ton/ha (GoI, 2013). Based on the straw to grain ratio (SGR) of 1.2 (Gadde et al., 2009a), the estimated harvestable rice straw yield on an average is 4.2 ton/ha. During harvest, straw is cut 6 in. from the ground so that straw removal does not affect soil carbon content. Most of the required data for inventory, given in Table 2 was collected from various government reports, scientific literature and was used only after cross verification and evaluation. The data used are region specific and average values of last 5 years. The emission factors

Table 1
Annual production, use and surplus rice straw in major rice producing states of India (Gadde et al., 2009a).

State	Total (kT)[a]	Domestic use[b] (kT)	Other use[c] (kT)	Surplus (kT)
West Bengal	16,009	8477	5931	1601
Uttar Pradesh	12,548	6781	2630	3137
Andhra Pradesh	11,312	0	10,181	1131
Punjab	10,436	1015	1073	8349
Tamil Nadu	6803	1380	4743	680
Orissa	6288	1674	624	3986
Haryana	3037	398	209	2429

[a] kT = kilotonnes.
[b] Domestic use includes bedding material for animals, building material for construction of houses in rural areas.
[c] Other use includes use as animal fodder and in paper industry.