CHAPTER 7

LIFE CYCLE ASSESSMENT OF RICE STRAW UTILIZATION PRACTICES IN INDIA

Open burning of rice straw is a serious issue in India which has an adverse impact on the environment. Currently, rice straw has some domestic uses and to some extent in industries also. This chapter will discuss four most realistic utilization practices of straw including: (1) incorporation into the field as fertilizer (2) animal fodder (3) electricity (4) biogas. Further, LCA is conducted to analyze the environmental impacts and find the potential practice amongst all scenarios. The results are also compared with LCA of ethanol production from straw to have detailed knowledge and identifying the best utilization practice.

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7.1 INTRODUCTION

Open burning is defined as the burning of residues and dead vegetation in the field [151, 287]. It is a human initiated activity to prepare the field for the next crop, remove residues, release nutrients for the next crop cycle and control weeds [152]. The field burning of rice straw is commonly practiced in the region where farmers have shorter time period to prepare the field for the next crop. Thus, farmers prefer to burn the residue in field, as is the case of rice straw in India [151]. Field burning is a process of uncontrolled combustion during which carbon dioxide (CO_2), is emitted into the atmosphere along with carbon monoxide (CO), un-burnt carbon (as well as traces of methane i.e. CH_4), nitrogen oxides (NOx) and comparatively less amount of sulphur dioxide (SO_2) [152]. India is suffering from the major problem of rice straw burning and its management has become a serious issue [288]. 1 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 non-methane hydrocarbon (NMHC), 2.9 NOx, 1.6 SO_2 and 10.4 total particulate matter (TPM) emissions [151, 171, 289]. The biomass managed predominantly through burning leads to significant air pollution and has now been banned across the country. Furthermore, nutrients accumulation occurs where straw is burnt and depletion in rest of the field [290]. 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 [170].

The rice crop in India is grown in most of its states as shown in Figure 7.1. However, the quantity of rice straw used is not significant from the perspective of current applications; it is used as a fodder, roofing material in domestic cook stoves especially in rural areas. The quantity of residue used varies largely from region to region and is therefore, characterized by great uncertainty.

There are several productive techniques that can be used for straw management such as composting [290] recycling in soil [170, 291], production of electricity [153, 292] and animal fodder. In addition, rice straw is also a promising feedstock for ethanol and biogas production [77, 293-295].

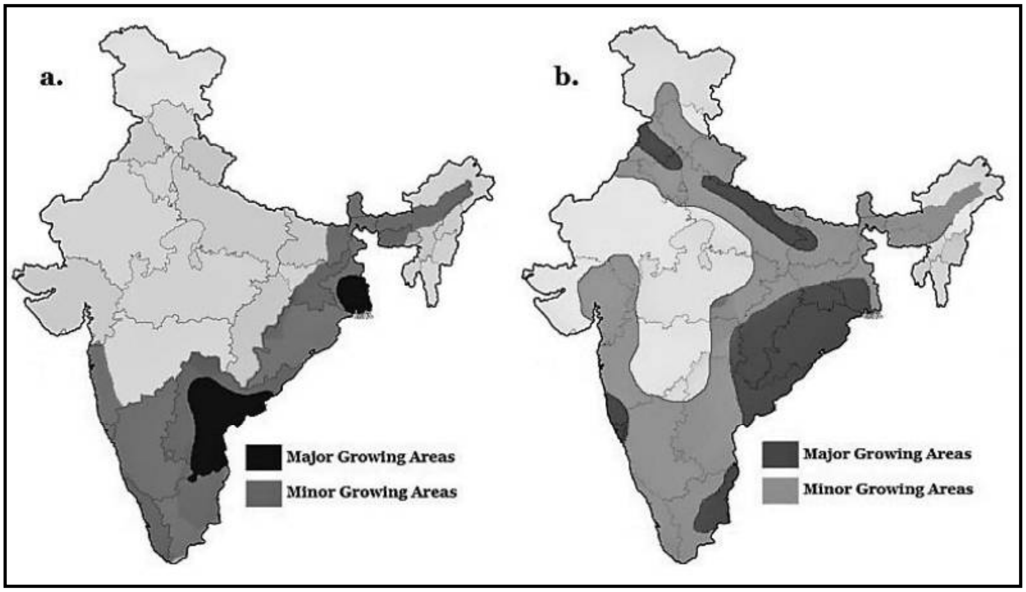


Figure 7.1 Major and minor rice producing states of India

The management of rice straw has agricultural and environmental implications particularly related to greenhouse gas (GHG) emissions and energy use [171, 290]. 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 7.1.

Table 7.1 Annual production, use and surplus rice straw in major rice producing states of India [170]

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

Life cycle assessment (LCA) studies are reported highlighting the management and utilization of rice straw in different countries such as, fertilizer in India [291, 296], fuel and fertilizer in Thailand [171], ethanol production [149], electricity production in Malaysia [153] and China. Several LCA studies have been reported in Thailand for use of rice straw for dimethyl ether (DME) production [164, 173], heat and power [292, 297]. In Philippines, a study was conducted where authors identified that early incorporation of straw in soil is most cost effective and environment friendly practice [298].

7.2 AIM OF STUDY

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 possible 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 discussed in above reported literature. The results of study will help to find out the environmental performance of different rice straw utilization pathways. The results would further assist government and policy makers in identifying, recommending and investing in sustainable utilization technology for rice straw management in India.

7.3 METHODOLOGY

LCA is used in current study to evaluate environmental performance of four straw utilization practices. The ISO standards 14040/44 were followed while conducting the LCA and accordingly methodology is divided in following sections.

7.3.1 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 food, third and fourth scenario as bioenergy. Therefore, it is not possible to designate a single functional unit in the study and comparison of results is based on processing of 1 ton straw.

The system boundary of the rice straw utilization systems is shown in Figure 7.2.

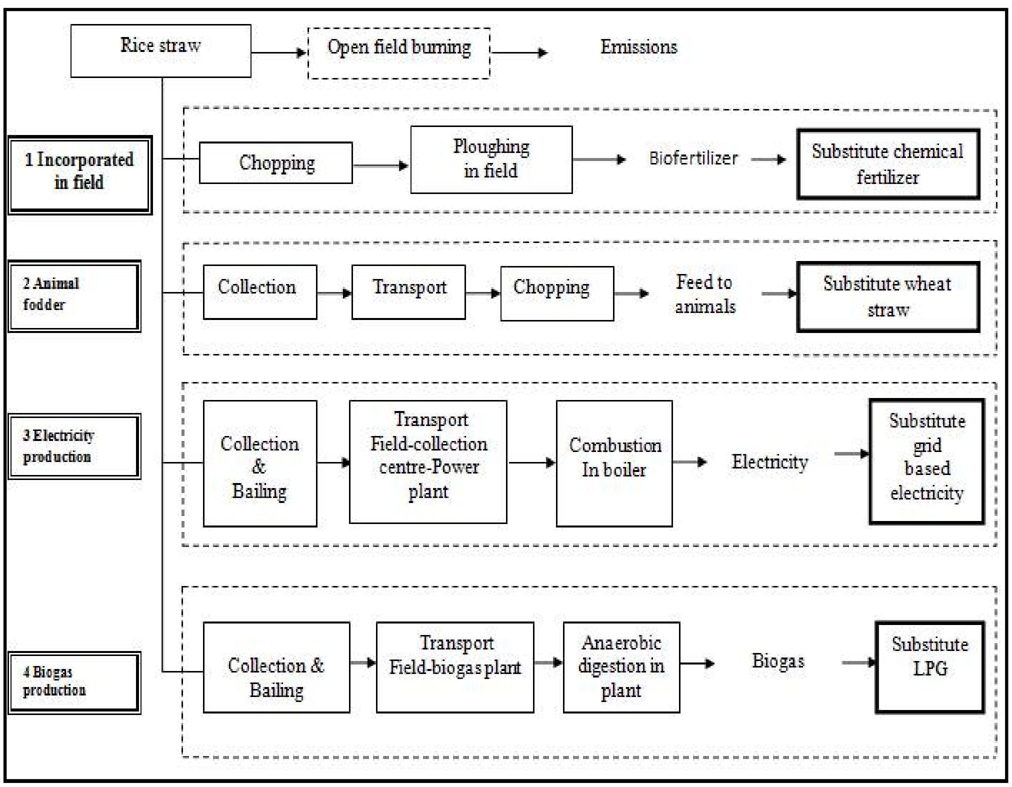


Figure 7.2 System boundary of rice straw utilization systems in India

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. 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.

7.3.2 LIFE CYCLE INVENTORY (LCI) AND PROCESS DESCRIPTION

The average yield of rice in the northern India is 3.5 ton/ha [256]. Based on the straw to grain ratio (SGR) of 1.2 [170], the estimated harvestable rice straw yield on an average is 4.2 ton/ha. During harvest, straw is cut 6 inches from the ground so that straw removal does not affect soil carbon content. Most of the required data for inventory, given in Table 7.2 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 derived were specific to Indian conditions, but due to lack of availability at certain processes, characterization factors have been adopted from other countries. Prior to the use of the data, all adjustments while calculating emission for processing 1 ton straw and assumptions considered are described in each scenario in following paragraphs.

Table 7.2 Inputs in Life Cycle Inventory (LCI) of rice straw utilization systems

Scenarios	Data collected	References	Substituted product
Incorporation into the field	Nitrogen content of straw, diesel required for chopping and ploughing, emissions from decomposition of straw	[171, 291]	28 kg of chemical urea
Use as animal fodder	Collection and bailing of straw, diesel required in shredding, inputs in agriculture of wheat, wheat and wheat straw price	[171, 257]	1 ton rice straw replace 1 ton wheat straw
Use for electricity production	Collection and bailing of straw, transportation distances, carrying capacity and mileage of vehicles, plant size, LHV of straw, conversion efficiency of plant	Personal communications; [155, 170]	1 kWh of straw based electricity replaces 1 kWh coal based electricity
Use for biogas production	Collection of straw, transportation distance, plant size, biogas production rate	[294, 295]	1MJ energy from biogas replaces 1 MJ energy from LPG

7.3.2.1 Rice Straw Incorporated into the Field

1 ton of dried rice straw contains organic material and nutrients such as C, N, P and K of about 383, 8, 1 and 19 kg, respectively [291] and these nutrients potentially return to soil when straw is incorporated into the field. The straw based fertilizers system could either be used in combination with organic manure or as alone [296]. Here, it is considered the later practice of incorporating straw alone in field and use it as a fertilizer which replaces the chemical fertilizer urea. The process starts with chopping of straw to an

appropriate size before incorporation and then followed by the same activity of land preparation for another crop. For chopping and ploughing one ton of straw requires about 16 L of diesel [291]. 1 ton straw contains ~ 8 kg N and this can replace about 28 kg of urea as fertilizer, based on the N ratio in urea [291].

7.3.2.2 Use of Rice Straw as an Animal Feed

In southern India, a large portion of rice straw is used as animal feed [151], whereas in northern India, wheat straw is used as feed for animals. Rice straw contains cellulose and is a good source of energy for livestock when supplied with other supporting ingredients such as in mixture with green fodder. While utilizing rice straw as fodder in northern India, an economic by-product wheat straw is substituted. Brief summary of grain, straw yield and emissions from the agricultural phase of both the rice and wheat in northern India is given in Table 7.3. It can be seen from Table 7.3 that production inputs of rice and wheat straw are different.

Table 7.3 Output from rice and wheat production in northern India

Particulars	Units	Rice	Wheat
Grain yield[a]	ton/ha	3.5	2.7
Straw yield[b]	ton/ha	4.2	3.2
CH_4 soil[c]	kg/ha	48	0
N_2O (soil and manure)[c]	kg/ha	0.9	0.1
N_2O (fertilizer)[c]	kg/ha	0.7	0.7
CO_2 (on farm and off farm)[d]	kg/ha	328	268
Total GWP (approx.)[e]	kg CO_2 eq./ha	1969	498

[a] Grain yield is average of last five years yield of rice and wheat in Punjab and Uttar Pradesh [256] [299]
[b] Straw yield is calculated based on the SGR of 1.2 [170]
[c] CH_4, CO_2 and N_2O is calculated from the use of fertilizer (NPK), diesel, labour during cultivation of rice and wheat [257]
[d] This CO_2 is of fossil origin (biogenic CO_2 are not included)
[e] Total GWP is calculated by normalizing CH_4 (1kg CH_4 = 25 kg CO_2 eq.) and N_2O (1kg N_2O=298 kg CO_2 eq) [300]. The emission from wheat cultivation is allocated between grain and straw using allocation factor of 0.29 for straw. Cultivation from rice are not included in this study but shown to compare the difference in emissions from rice and wheat systems

It is assumed that 1 ton of rice straw will substitute 1 ton of wheat straw while using as fodder. It is an assumption based on the personal communications with farmers both in Northern and Southern India. Wheat straw is an economically valuable product; therefore, share of environmental burden of wheat straw from wheat cultivation is allocated using economic allocation. The allocation factor for wheat straw and grain is determined by the Equation 7.1 [171]

$$\mathbf{AFstraw = SGR * \frac{Pstraw}{Pwheat+SGR*Pstraw}} \qquad \mathbf{Eq. 7.1\ [171]}$$

Where, AF_{straw} is allocation factor for straw,
SGR= straw to grain ratio, i.e. 1.2 [170]
P_{straw} is farm to gate price of straw, i.e. 4500 Indian rupee (INR)/ ton (or 69.1 US $/ton)
P_{wheat} is the price of wheat, i.e. 14000 INR/ton (or 215 US $/ton)

An allocation factor of ~ 0.29 is obtained for wheat straw using above equation and parameters. Collection of straw is manual and after collection straw is chopped into smaller size on the field and then transported to villages by bullock carts. Therefore, emissions from chopping only are included in the study. Straw chopping consumes diesel and hence equivalent emissions are considered for both rice and wheat straw. The emission factor for straw chopping is given in Table 7.4. The CH_4 emissions from animal dung are not considered, assuming that dung produced from rice and wheat straw will have similar emissions.

Table 7.4 Emission factors used in various on farm and off farm activities

Activities	Units	CO_2	CO	NOx	SO_2	Particles
Straw ploughing[a]	g/MJ	515.2	5.1	1.3	1.4	0.2
Straw chopping[b]	g/MJ	334	1.3	2.4	2.5	0.5
Bailing[c]	g/MJ	72	0.1	0.8	0.002	0.01
Transportation						
Tractor[d]	g/km	515.2	5.1	1.3	1.4	0.2
Truck[d]	g/km	515.2	3.6	6.3	1.4	0.3

[a]Tractor is used during straw ploughing that consume 16L/ha diesel [171] and have energy content of 38.6 MJ/L. Emissions from one ton straw ploughing is calculated based on the average straw yield of 4.2 ton/ha using emission factors of tractor for transport
[b]Emission factor for chopping is based on electricity consumption in shredding knife mill used to cut the straw. For one ton of straw to cut into 5 mm size, 7.6 MJ electricity is used when motor of 7.5HP runs at a speed of 200 kg/hr straw. This data is collected from pilot plant at Bioenergy Research Centre, Faridabad.

[c]Due to lack of data on emissions from bailing, emission factors are derived from bailing of wheat straw in Sweden [294]
[d]g/km emissions (Diesel-net, 2014) are converted to g/MJ by calculating total diesel consumption in loaded and unloaded transport and multiplying it with the energy content of diesel *i.e.* 38.6 MJ/L [71]

7.3.2.3 Use of Rice Straw for Electricity Production

Utilization of rice straw for electricity production is being promoted in some parts of the country with an objective of producing renewable energy. Punjab, a state located in northern India has equipped with number of power plants so as to utilize about 8 Mt of straw which is available as surplus. In Punjab, around 10 Mt biomass is produced, out of that 0.48 Mt straw is being used in 7 biomass based power plants for generating 62.5 megawatt (MW) power in the state [301]. Largest plant of 12 MW near Ghanaur village in Patiala is functioning for the last two year which consumes 350- 400 ton of straw per day [301]. The plant is able to meet the electricity demand of nearby villages. The Punjab Energy Development Agency mandated to utilize 4.5Mt of straw from total surplus available by 2017 in 50 plants generating 509.5 MW power. The high metal content, slagging, fouling and sintering causes problem in operation, however, with the advancement of technologies, these issues in the functioning of the power plant are resolved.

The system boundary starts with straw collection, bailing, transportation and electricity production. Straw collection is manual followed by bailing where, 7 L/ha of diesel is used [153]. The average mass of rice straw bale is 20 kg. Transportation is a two step process where rice straw from field is first transported to the collection centre (~10 km) with a tractor trolley of capacity 1.5 ton and consuming diesel 4.5 and 5.5 km/L in loaded and unloaded conditions respectively. Rice straw from the collection centre is then transported to the power plants (~50 km) with truck of capacity 20 bales and diesel consumption of 5.5 and 6.5 km/L in loaded and unloaded conditions respectively. Transportation distances, carrying capacity and mileage of vehicles is based on the personal communication with industry experts at M/s Bermaco Private Limited, Punjab. The emission factors for shredding, ploughing, bailing and transportation are given in Table 7.4.

Rice straw based power plant uses fire grate boiler combined with the steam turbine for electricity generation. Rice straw characteristics and chemical composition are critical factor influencing the operation and maintenance of straw-fired power plants. The proximate analysis results shows that straw contains 10% moisture, 65% volatile matter, 11.3% fixed carbon and 13.7% ash. Ultimate analysis shows the carbon (45.2%), hydrogen (6.5%), nitrogen (0.8%), oxygen (47.5%) and sulphur (0.009%) content of rice straw [302, 303]. These are useful parameters in determining the lower heating value (LHV) of fuel, design and energy conversion system of the product. Equation 7.2 [170] is used to determine the LHV of solid fuel in MJ/kg based on the average values from ultimate analysis of straw.

$$\mathbf{LHV = 34.8 * C + 93.9 * H + 10.5 * S + 6.3 * N - 10.8 * O - 2.5 * W \quad Eq. 7.2}\ [\mathbf{33}]$$

Where LHV is lower heating value of straw, C is carbon, H is hydrogen, S is sulphur, N is nitrogen, O is oxygen and W is water content of straw

The overall efficiency of the power plants is 30% [155]. Electricity output power from rice straw is calculated using Equation 7.3.

$$\mathbf{E\ rice\ straw = Amount\ of\ straw\ burnt * LHV\ of\ straw * Conversion\ efficiency\ Eq. 7.3}\ \text{Error! Bookmark not defined.}$$

Where, E rice straw= Electricity output from rice straw in kWh
Amount of straw burnt = 1 ton
LHV= Lower heating value of straw, *i.e.* 16.4 MJ/kg
Conversion efficiency = 30% efficiency of plant

The factors used to calculate emissions during energy production from rice straw and coal based electricity are given in Table 7.5.

Biogenic emissions of CO_2 from rice straw based power plant are considered zero since amount of CO_2 produced during combustion is utilized during photosynthesis while growing crops. The utilization of straw based electricity displaces the coal based electricity, therefore, in system expansion, 1kWh electricity generated from rice straw displace 1kWh units of electricity produced from coal.

Table 7.5 Emission factors for energy production from different sources

Energy systems	Units	CO_2	CH_4	CO	NOx	SO_2	Particles
Electricity (Rice straw) [a)]	kg/kWh	0.36	0.0003	0.0009	0.0007	0.00004	0
Electricity (Coal)[b]	kg/kWh	1.21	0.03	0.009	0.005	0.0075	0.002
Biogas production[c]	kg/GJ	0.57	0.36	0	0	0	0
Biogas combustion	kg/GJ	NA[d]	0.043	0.19	0.038	0.08	0.18
LPG[e]	kg/GJ	140.2	0.13	2.7	0.22	0.67	0.46

[a] Includes emission only from the boiler of rice power plant [153],[b] Includes fuel cycle emissions and are average values based on studies [305][c] Includes emissions from electricity used in stirring of digester
[d] CO_2 emissions from biogas combustion are biogenic and hence considered not applicable
[e] Includes emissions from extraction, refinery, storage handling transport distribution (SHTD), bottling and combustion [295]

7.3.2.4 Use of Rice Straw for Biogas Production

Biogas production from anaerobic digestion of straw is a promising option of achieving environmental benefits and producing energy. Currently, biogas plants are at the farm scale where straw can be directed easily to the plant to produce biogas [295]. Therefore, rural people used the biogas as a substitute for liquefied petroleum gas (LPG) for cooking. In 2014-15, about 20,700 lakh m^3 of biogas is produced in the country which is equivalent to 5% of the total LPG consumption in the country. The Government is also extending substantial subsidy for setting up of new biogas plants as it does not require any fancy storage systems and rather can be used directly in the households. Therefore, the use of biogas at farm scale has an added advantage over LPG because of the avoidance of processes like storage, transport and handling are avoided. The produced biogas is supplied directly through pipelines in nearby houses. In current study, system expansion is conducted based on the current use of biogas as cooking fuel which displaces LPG.

The process includes straw collection, transport, production and its end use in cooking. Collection of straw is manual and bailing is similar as explained in the above system. The average distance of biogas plant from the field is estimated to be 5 km and transportation of rice straw from field to plant is by tractor trolley. The distance and mode of transportation is adopted after consultation with the villagers. The biogas system is fixed dome, 2 m^3 household type, anaerobic digester (AD) operating in continuous feeding mode for 350 days/year operating cycle and 10 years of operational life [295]. The plants consist of one stage AD operating at 30-40 °C, where straw is mixed with water and cattle dung to reach desired solid content of 10%. The emissions from digester are determined based on the electricity used in digestion process. For one ton of straw digestion, 290 MJ electricity for stirring of digester is required [294]. Heating is not required in India as ambient temperature is sufficient to provide the heat. Emission factors for the production and combustion of biogas and LPG based on previous literature studies are given in Table 7.5.

7.4. RESULTS AND DISCUSSION

The results are calculated using CML 2 method [300] considering four different environmental impact categories: Global warming potential (GWP) over a 100 year time horizon, expressed as kgCO_2eq. (2) Eutrophication potential (EP) expressed as kgPO_4eq. (3) Acidification potential expressed as kgSO_2eq. (4) Photochemical oxidants creation potential (POCP) expressed as kgC_2H_4 eq. The selection criteria of environmental impact categories is based on the current global environmental problem and based on the previous studies of [171, 306].

7.4.1 GLOBAL WARMING POTENTIAL (GWP)

The GHG emissions emitted during each scenario is given in Table 7.6. Burning is considered as a base case and accordingly all the calculation of GWP reduction for each system is performed. Table 7.6 shows a net GWP benefits in the order of; electricity production > biogas production > animal fodder > incorporated into the field. One ton of rice straw produces 1367 kWh electricity, which can substitute an equal amount of coal based electricity which emits about 2.3 times higher CO_2/kWh electricity. Transportation of straw alone contributes about 92% of GWP amounting to 198 kgCO_2eq.

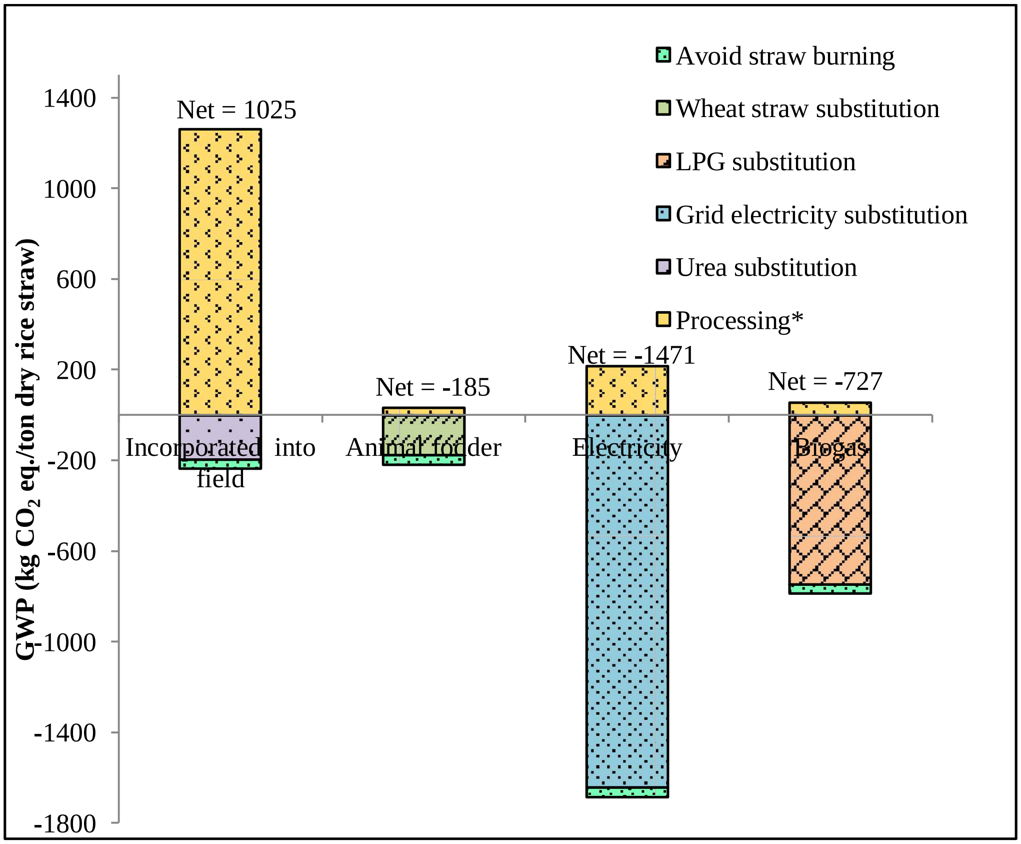
One ton of straw produces 7.1 GJ energy from biogas which replaces equivalent energy from LPG [294]. The emissions of CO_2 from LPG production are much higher during the process of extraction, refining, storage, transport, handling and bottling. The GWP benefits obtained from use of straw as an animal fodder are comparatively lower to other systems as it replaces wheat straw which has relatively lower GWP with respect to electricity and LPG.

Table 7.6 Impacts on global warming potential (kgCO_2eq./ton of dry rice straw) of four rice straw utilization systems in India

	Incorporated into field	Animal fodder	Electricity production	Biogas production
Activities				
Straw chopping	47	32	NA	NA
Straw ploughing[a]	1213	NA	NA	NA
Collection & bailing	NA	NA	7	7
Transportation	NA	NA	198	19
Combustion in boiler	NA	NA	9	NA
Anaerobic digestion	NA	NA	NA	10
Total GHG emissions	**1260**	**32**	**214**	**36**
GHG credits from substituted products				
Urea substitution	-194	NA	NA	NA
Wheat straw substitution	NA	-176	NA	NA
Grid electricity substitution	NA	NA	-1644	NA
LPG substitution	NA	NA	NA	-722
Avoidance of open field burning	-41	-41	-41	-41
Total GHG credits	**-235**	**-217**	**-1685**	**-763**
Net GWP	**1025**	**-185**	**-1471**	**-727**

[a]straw ploughing includes emissions from decomposition of straw
[*]NA means not applicable

The overall GWP increase, when rice straw is incorporated into the field due to release of 47 kg CH_4 and 0.13 kg of N_2O [291] and could replace 17 kg fertilizer and there is also improvement in the yield. Crops grown on dry land with straw incorporated into field normally have GHG emission reductions but in case of rice opposite is the trend because a higher proportion of available C is released as CH_4. CO_2 and CH_4 in soils are produced through various processes such as biological oxidation of soil organic matter (SOM), decomposition of crop residues and root respiration. Nitrification and denitrification are the two major microbial processes responsible for N_2O emission from flooded rice soils. Therefore, a net increase in GWP is observed along with increase of SOM and yield. GWP increases while using rice straw incorporated into the field, whereas net reduction is obtained in other three systems as shown in Figure 7.3.



*Includes rice straw processing to fertilizer, animal fodder, electricity and biogas in four systems respectively

Figure 7.3 Global warming potential (GWP) of rice straw utilization systems

While comparing the results for rice straw based electricity in previous studies, Malaysia, for example, has higher GWP (0.84 $kgCO_2$eq./kWh) [153] and Thailand has lower GWP (0.043 $kgCO_2$eq./kWh) [297] than India (0.15 $kgCO_2$ eq./kWh). Transportation distances play major role in the GHG emissions and average distance of power plant from collection centre in Malaysia is 100 km, 32 km for Thailand whereas the distance is kept 50 km in

India. Moreover, electricity production in Malaysia also includes emissions from cultivation of rice and collection process of rice straw is fully mechanized whereas straw is collected manually in India.

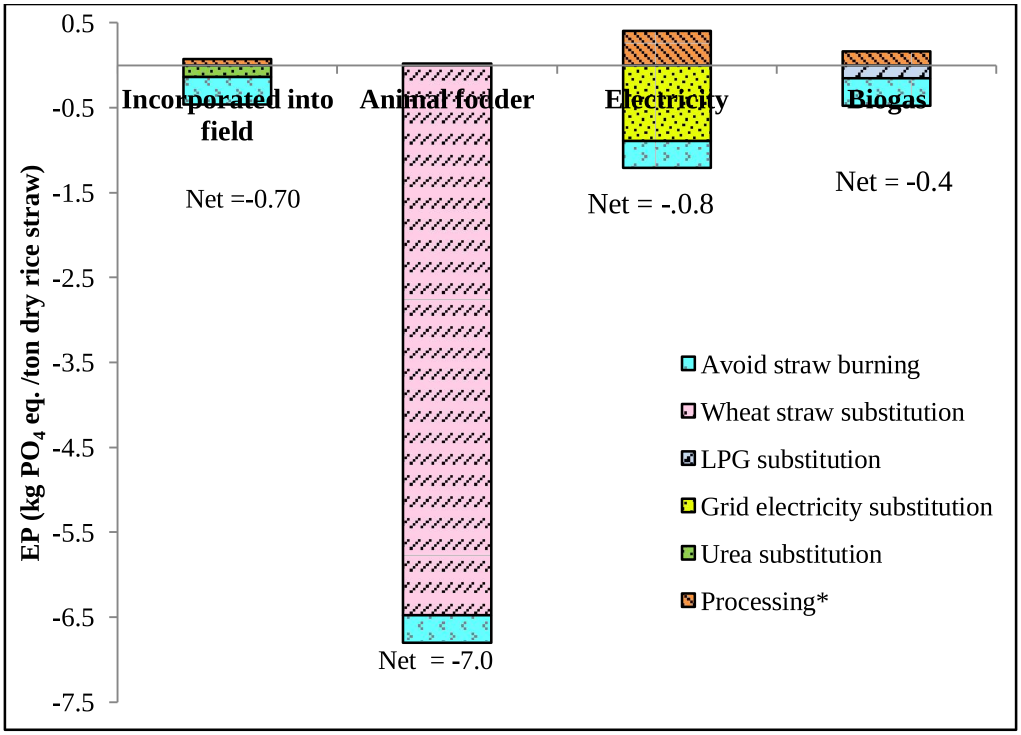
GHG emissions from farm scale biogas production in Sweden is 12 $gCO_2eq.MJ^{-1}$ [294] and are comparable with emissions from biogas production in India (11 g CO_2 $eq.MJ^{-1}$) as the distances and methane emission losses are almost equivalent in both the countries.

The results of emissions from rice straw incorporation into the field (1213 $kgCO_2eq.$) are similar to the study conducted in China [307] where contribution of rice straw to GWP is 1365 $kgCO_2eq./ha$ respectively. This practice provides a source of readily available C believed to induce a higher CH_4 release from rice paddies and influence N_2O emissions. Decomposition of organic material is the source of methanogenic substrates in early stage of rice growing. LCA of rice straw utilization as animal fodder is not reported in scientific literature. Therefore, comparative analysis is not included.

7.4.2 EUTROPHICATION POTENTIAL (EP)

The waste water discharge and air emissions of NOx and NH_3 into phosphorous equivalents is defined as EP and a comparative EP of the four rice utilization systems is shown in Figure 7.4 and are in the order: animal fodder > electricity production > left in field > biogas. The major advantage of straw utilization is the avoidance of the straw burning, contributing to impact of 0.3 kg PO_4 eq./ton straw. The highest reduction in EP of 7.0 kg PO_4 eq./ton straw can be achieved while utilizing straw for fodder. The emissions from fertilizers production and their use while growing wheat are responsible for the eutrophication process.

In electricity production, the diesel consumption during transportation contributes significantly to the impact (0.40 $kgPO_4eq.$) but the net benefits of 0.8 $kgPO_4eq.$ are obtained in substituting emissions from straw based electricity. Transportation and disposal of bottom ash contributes to EP. There is a difference between the use of rice straw as an animal fodder and electricity because of the different displaced products during system expansion. The avoided emission from use of fertilizers during wheat production is an added advantage in using rice straw as an animal fodder.



*Includes rice straw processing to fertilizer, animal fodder, electricity and biogas in four systems respectively

Figure 7.4 Eutrophication potential (EP) of rice straw utilization system

Incorporation of straw into field releases nitrogen which can partially replace fertilizer and hence proves to be beneficial in the net EP impact of 0.5 kg PO_4. The leaching and denitrification process from fertilizers causes eutrophication by emitting NOx and NH_3 into soil.

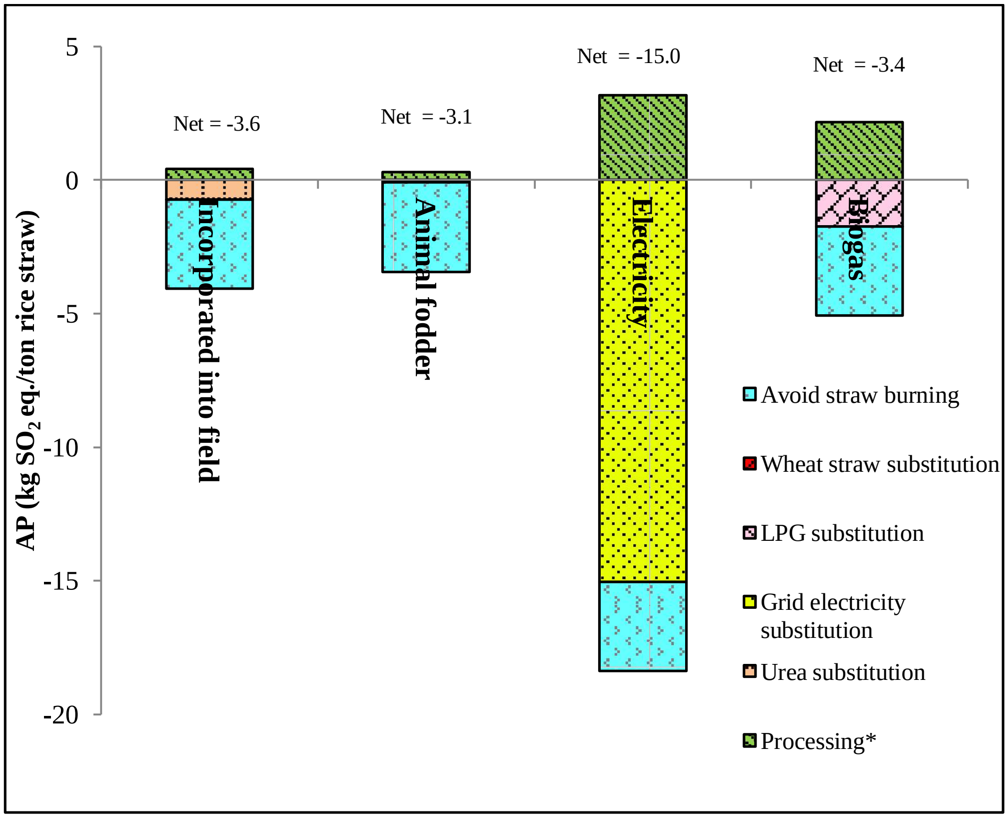
When rice straw is incorporated into the field, net reduction of 0.5 kg PO_4 eq. is achieved. The nitrogen content of straw is lower than substituted fertilizer and therefore, leaching of NOx and NH_3 is lower. The replacement of fertilizer leads to higher emissions of NOx and NH_3 into soil (0.13 kgPO_4eq.) than straw (0.07 kgPO_4eq.). Rice straw based biogas gives the lowest net reduction of 0.4 kg PO_4 eq. among all the scenarios, because, the production and combustion process of biogas releases large amount of NOx (0.16 kgPO_4eq.) equivalent to the EP of the replaced LPG system. Therefore, the EP benefit while using straw for biogas production is due to avoidance of open burning of straw.

The EP of straw based electricity in Malaysia is 0.2 kgPO_4eq./kWh [153], which is 80% higher than straw based electricity in India (0.1 kgPO_4eq./kWh). The reason for higher EP in Malaysia is emissions from fertilizers used during agricultural phase.

When one ton dry straw is incorporated into the field as fertilizer, the net EP benefits of 0.5 kgPO_4eq. obtained are similar to the Thailand 0.4 kgPO_4eq. due to the emission factors for substituted fertilizer and straw burning are similar in both the countries [171]

7.4.3 ACIDIFICATION POTENTIAL (AP)

The measure of the acidifying potential is calculated through the conversion factor of sulphur oxides, nitrogen and ammonia into acidification equivalents and net reduction in AP while utilizing rice straw is shown in Figure 7.5. The net AP benefits follow the trend: electricity > incorporated into the field > animal fodder > biogas. The open field burning of straw resulted in a substantial amount of NOx and SO_2 emissions contributing to 3.3 kgSO_2eq./ton straw. Utilizing straw can avoid these emissions, *i.e*. electricity gives the highest net AP reduction of 15.0 kg SO_2 eq./ton straw. SO_x emissions are quite high in coal based power plants, which can be avoided using biomass based electricity.



*Includes rice straw processing to fertilizer, animal fodder, electricity and biogas in four systems respectively

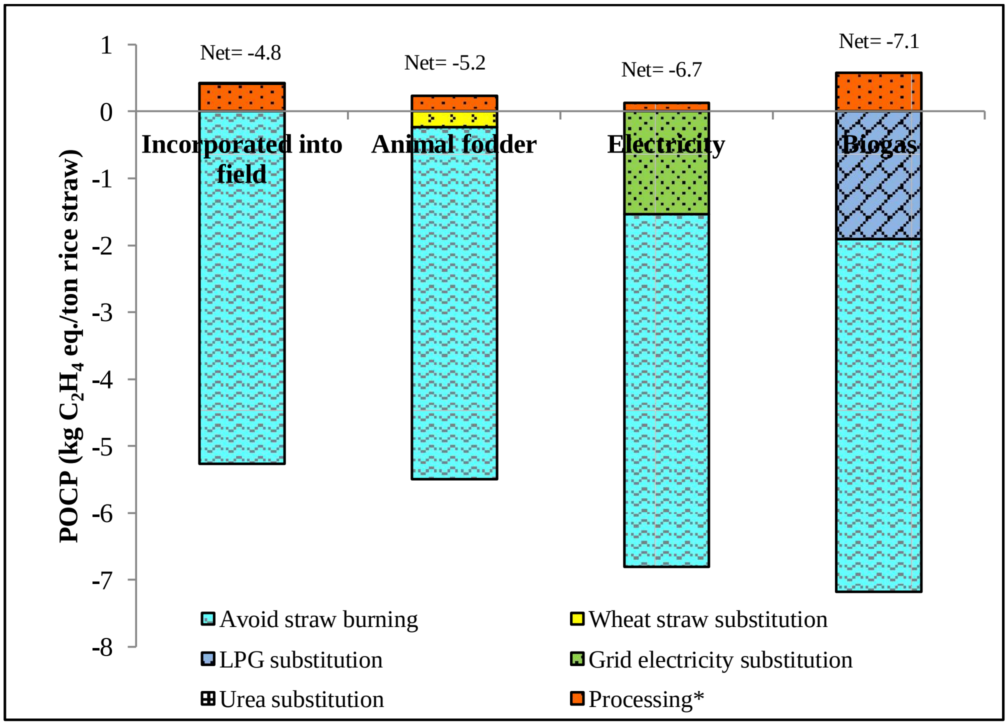
Figure 7.5 Acidification potential (AP) of rice straw utilization systems

The second highest benefit is obtained when straw is incorporated into the field (3.6 kg SO_2 eq./ton straw) and fertilizer is replaced. The NH_3 emission from fertilizers contributes to the impact which, in case of using straw is reduced. In case of animal fodder, the emissions responsible to the impact are only during chopping and are insignificant. The AP benefit in this case is seen only in avoiding the burning of straw. The net AP benefit in biogas production is 3.4 kg SO_2 eq./ton straw, where processing of straw to biogas is responsible for 2.1 kg SO_2 eq./ton straw and 1.7 kgSO_2eq./ton straw can be avoided by substituting LPG. The electricity used during stirring of digester is responsible for NOx and SOx emissions.

The AP of straw based electricity in Malaysia is 6 kgSO_2eq./kWh [153] which is 3 times higher than India (2 kgSO_2eq./kWh) . The reason is attributed to higher diesel consumption in mechanized agriculture and transportation. While comparing, AP results of processing one ton of straw to electricity and fertilizer with study in Thailand [171]; the net benefits are 2.3 and 2.6 $kgSO_2eq.$ respectively. The AP benefits in electricity production in Thailand are quite lower with respect to India (15.0 $kgSO_2eq.$/ton straw), since, the Thai grid electricity today has relatively lower emissions of SO_2 and NOx as better quality of coal is used for electricity generation. The AP results of straw based fertilizer are comparable in both the studies.

7.4.4 PHOTOCHEMICAL OXIDANT CREATION POTENTIAL (POCP)

The POCP is associated with the emissions of NOx, CO, CH_4 and particulates resulting in the formation of smog. The burning of straw is the major source of particulate matter and hence contribute significantly to the POCP. Utilizing straw avoids 5.2 kg C_2H_4 eq. from burning. The comparative results of POCP are shown in Figure 7.6 and follow the trend: biogas > electricity > animal fodder > incorporated in the field. Biogas production gives net benefits of 7.1 kg C_2H_4 eq. since; biogas replaces LPG resulting in higher amount of NO_X, CH_4 and particulates (2.0 kgC_2H_4eq). A net reduction of 6.7 kg C_2H_4 eq. is obtained using straw based electricity, which replaces coal based electricity having higher particulates and NOx emissions (1.5 $kgC_2H_4eq.$) Rice straw when used for fodder and incorporated in the field give reductions of 5.2 and 4.8 $kgC_2H_4eq.$ respectively. The use of diesel in ploughing and chopping emits NOx and particulate matter and contributes to the impact. The major POCP benefit in all the cases is mainly due to avoiding the burning of straw. Due to unavailability of literature for this impact category, we are unable to compare the results.



*Includes rice straw processing to fertilizer, animal fodder, electricity and biogas in four systems respectively

Figure 7.6 Photochemical oxidant creation potential (POCP) of rice straw utilization systems

7.5 SENSITIVITY ANALYSIS

Among the four systems studied, rice straw based electricity production results in highest benefits in GWP. As reported in literature, the two parameters, power plant distance and electricity conversion efficiency in the plant [153] could result in uncertainty in the results, therefore, with a view to identify the impact of change in these parameters, sensitivity analysis is conducted. Plant efficiency leads to significant impact to the GWP, as reported in Malaysia [153], China [308] and Thailand [171]. Effect on GWP is studied for ±10% variation in electricity conversion efficiency form base case (30%) and is shown in Figure 7.7 (where negative bars in graph shows the credit/or savings in GWP). The net GWP savings increases from 1388 to 1936 kgCO_2eq. at 30 to 40% efficiency, respectively, whereas reduces to 841 kgCO_2eq. at 20% efficiency. This variation is quite similar to the results in the study of rice straw power plant based in Malaysia, where 0.5 % increases in plant efficiency results in reduction of 2.3 kg CO_2 eq. GWP [153].

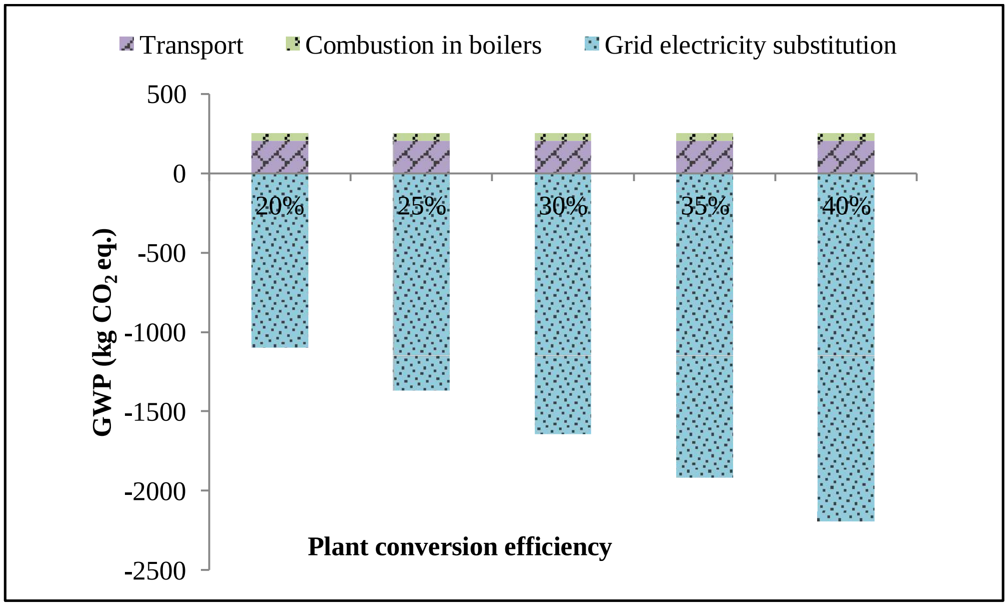


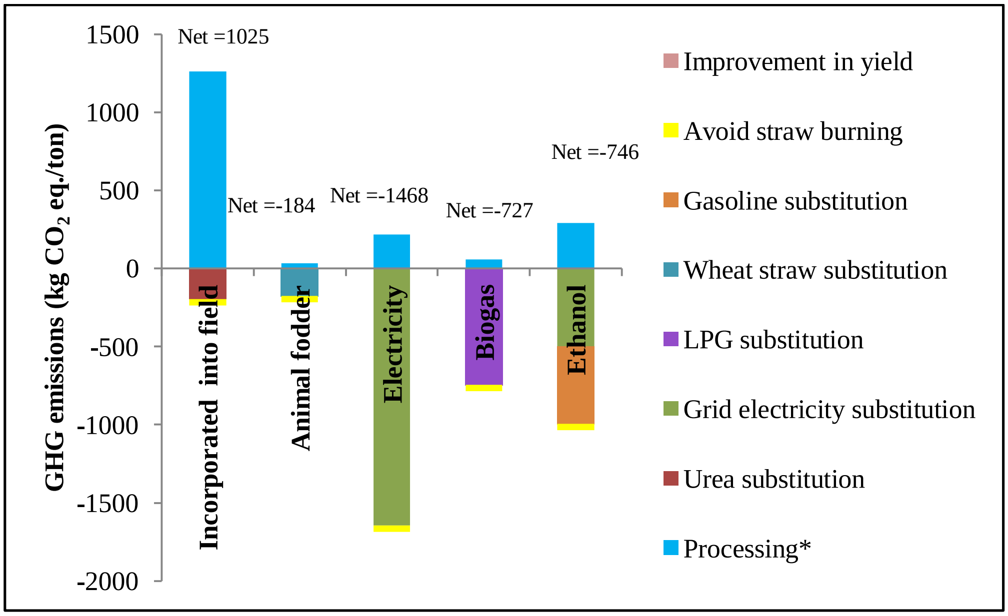
Figure 7.7 Sensitivity analysis on effect of varying transportation distances on GWP

Straw transportation is another important factor having implication on the GWP. This is a two step process wherein straw is first transported from field to collection centre by tractor (T1) followed by transport to power plant with truck (T2). Variation of ±5 and ± 25 km in distance is considered for T1 and T2 respectively. This selection of variation in T1and T2 distance is based on personal communication with experts. T1 shows 2.1% increase in GWP for each 1 km and T2 shows 11% increases in GWP for each 5 km increase in distance. For 1 km increase in distance T1 has higher GHG emissions than T2. These results are similar to the studies conducted in Ireland and Malaysia wherein for each 10 km increase, T1 has 0.97% while T2 has 0.13% increase in GWP [153]. It is evident from literature too, that trucks having higher capacity and mileage than tractors shows better efficiency and is better option to use for longer distances transport [153]. Most of the literature reports that plant location should be within 20 km radius from the farms [297] so as to reduce GWP impact.

7.6 COMPARATIVE LCA OF RICE STRAW UTILIZATION PRACTICES

LCA has previously been conducted for ethanol production from rice India. The motivation behind this comparison is to identify the practice that can provide the best solution to various environmental and energy issues of country. The system boundaries are comparable for all the practices as it starts with the harvesting and collection of straw, followed by transport, processing of straw to the end-product and finally the use phase. System expansion is applied to account for the emissions by the displaced product. The GWP results of five practices is shown in Figure 7.8 and include processing of 1 ton straw to the product, credits obtained in emissions while avoiding straw burning and substituting the reference products respectively.

The utilization of one ton rice straw to electricity resulted in highest net emissions (1468 kgCO_2eq.), followed by ethanol production (746 kgCO_2eq.), biogas (727 kgCO_2eq.) and animal fodder (185 kgCO_2eq.) whereas incorporation into field resulted in increase of GHG emissions. The formation of methane from the decomposition of straw is responsible for higher GHG emissions during incorporation. It is interesting to note that although energy produced from processing of 1 ton straw to ethanol is higher (including co-product) as compared to electricity, but the later practice is better in GHG savings.



* Processing include collection, transport and conversion of rice straw to various end product.

Figure 7.8 GHG emissions of different rice straw utilization practices in India

The difference in emission among these two arises due to different processing technologies and the displaced product. If we utilize rice straw for electricity production, equivalent amount of bio-electricity replaces equivalent coal based electricity. The GHG from coal based electricity are by-far the most intensive source of GHG emissions that are avoided using bio-electricity. Moreover, the inputs used in ethanol production chain; e.g. enzyme and chemicals are also responsible for higher GHG emissions during production chain. Comparing rice straw ethanol with biogas, there is no significant difference. Therefore, it can be concluded that utilization of rice straw for bioenergy production in India is a promising alternative to conventional sources. However, optimum utilization practice will depend upon the requirement of the end product. Therefore, the utilization of rice straw for ethanol is encouraged so as to achieve the 20% blending target by 2017, mandated by the Government of India [260].

7.7 CONCLUSIONS

The LCA of four rice straw utilization systems results show that straw utilization for electricity and biogas production results in the highest environmental benefits in GWP, AP and POCP and utilization for fodder results in the highest benefit in EP. The sustainable use of straw can provide clean energy to ever increasing demand of energy in India. The issues regarding the policy for encouraging the utilization of agricultural residue for electricity production in rice cultivating areas should be analyzed in depth in the near future. The local community should also invest in expanding the number of biogas plants in the villages.