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Assessment of Rice Residues as Potential Energy Source in Pakistan

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Abstract:

Pakistan produces a huge amount of biomass wastes such as rice straw (RS) and rice husk (RH), wheat straw (WS), and other biomass wastes that are being burned in the field after crop harvest to prepare the land for the next crop. Biomass is known as a potential energy source that can be effectively utilized as an alternative to fossil fuels. This study aims to assess the energy potential and gaseous pollutant emissions from rice residues such as RS and RH. The Energy potential of crop residues in Pakistan was estimated by considering the residual characteristics such as residue to crop product ratio, moisture level and lower heating value of dry biomass obtained from the South Asian countries. The mathematical models were defined for the assessment of amount of residues, available energy potential, and emissions of gaseous pollutants. The estimated amount of rice residues found to be 10147.65 thousand tons of dry biomass. The theoretical and available energy potential of the rice residues were estimated as 159219 TJ, and 100,431 TJ, respectively. Based on dry matter fraction and proportion of crop residue burnt, the total amount of crop residue burnt for RS and RH were 1356.38 thousand tons and 307.7 thousand tons respectively. Total emissions from burning of rice residues were estimated as 1749.59, 27.639, 2.432, 1.265, 4.997, and 0.549 Gg for CO_2, CO, NO, NO_2, NOx, and SO_2, respectively. It was concluded that the crop residues generated in Pakistan can be effectively utilized as an alternative energy source, to reduce electricity demand supply gap, reliance on fossils fuels, and lower contribution to global warming.

Keywords: *Rice Husk; Rice Straw; Energy Potential; Pollutant emissions; Crop residues*.

1 Introduction

Pakistan is currently facing confronting industrial and economic challenges since couple of decades due to various factors such as energy crisis, rapid rising population, changing lifestyle of people [1][2]. Among them, the energy crisis are caused by poor planning and mismanagement of energy sector in terms of poor market instruments, inefficient energy mix and higher transmission and distribution losses which has ultimately caused reduced employment and production of industries, and increased electricity prices [3].

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The electricity is mainly produced from conventional thermal resources sharing 58.4% followed by hydro 31%, nuclear 2.8 %, and other renewable sources 2.4% [4].

The thermal energy sources for electricity generation cannot be relied as primary energy sources due to their high prices and adverse environmental impacts [5].

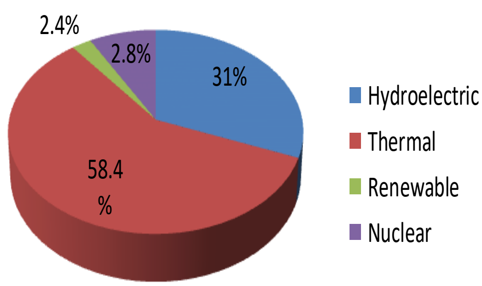

Fig. 1. Sources contribution in Electricity Generation [4]

Utilization of fossil fuels for electricity generation has resulted greenhouse gases (GHGs) emissions into the environment [6]. The major emissions are sulphur oxides (SOx), sulphur dioxide (SO_2), and nitrogen oxides (NOx), carbon dioxide (CO_2), carbon mono oxide (CO) and particulate matters (PM) [7][8]. The overall emissions in Pakistan are estimated to increase in future from 557 Million tons CO_2 equivalent (Mt CO_2-eq) in 2020 to 4621 Mt CO_2-eq in 2050 as shown in Fig. 2 [9]. The trend of utilizing biomass as a potential source has been increasing throughout the world because of certain advantages such as abundant availability, lower environmental impacts through modern biomass conversion technologies, increased energy security and supply, development of rural areas and job opportunities. Biomass is more economical in comparison with other renewable energy sources because of less capital and investment cost per unit of production [10]. Pakistan is still inefficient to implement advanced technologies for efficient utilization of alternative renewable energy resources. However, some of the renewable energy projects are installed such as biomass [11], Solar [12], Wind [13]. The different energy sources and their conversion routes are presented in the Fig. 2 [14].

Pakistan is an agrarian country in which the contribution of agriculture sector in country's Gross Domestic Product (GDP) is 21%. The major crops are rice, sugarcane, wheat, cotton, and maize producing waste in the form of straw and husk, bagasse, wheat straw (WS), cotton straw and corn stover respectively [4].

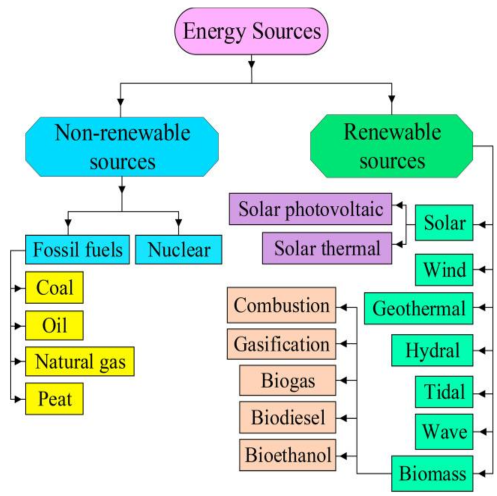

Fig. 2. Classification of energy resources [14]

Pakistan is an agrarian country in which the contribution of agriculture sector in country's Gross Domestic Product (GDP) is 21%. The major crops are rice, sugarcane, wheat, cotton and maize producing waste in the form of straw and husk, bagasse, wheat straw (WS), cotton straw and corn stover respectively [4]. Rice is considered as one of the most commonly produced and consumed grains in the world population. It is known as prominent staple food in many countries as it is rich in proteins, lipids, carbohydrates, phytic and phenolic acids, minerals, vitamins B and E [16].

Agricultural residues are produced from harvesting and processing of crops and are categorized as primary and secondary residues. Primary residues such as RS, WS, and sugar cane tops are those residues which are produced in the field when harvesting the crop, while secondary residues such as rice husk (RH), wheat husk (WH) and bagasse are produced at processing mills. Primary residues have lower availability because of difficulty in the collection, and farmers utilize as fertilizer, animal feed. Availability of secondary residues is comparatively high at the processing mills with little handling and transportation cost [18]. Being an agrarian country, Pakistan produces massive quantity of crop residues like stems, leaves, and seed pots that can be efficiently utilized as energy source. Huge amount of crop residues such as RS, RH, WS, sunflower stems, garden biomass wastes, dates, mangoes, and orange tree biomass are burned in the field after crop harvest every year to prepare the land for next crop [19]. The amount of crop residue directly depends upon the crop production. The amount of crop residue generated directly depends upon the yield of crop. Rice crop has two main types of residues, the field residues such as RS and the process residues such as RH and bran. RS is dry stalks of cereal plants collected at the time of harvest in the field. RH is outer most layer of rice grain and is known as process residue. Rice bran is used as cattle, poultry and fish food [20][21]. RS is used as feedstock and bedding material for livestock, domestic fuel as well as building material in rural areas [22]. The burning of crop residues is a common activity in developing countries because of unawareness of benefits related to its alternative uses as an energy source [23][24]. Crop and agricultural residues are being used as domestic fuels for heating and cooking purpose since ancient times. Almost half of the people in the world especially in developing countries are utilizing the agricultural and crop residues as a primary energy source and are known as fourth major energy source after coal, gas and oil [25]. After harvesting rice crop, the farmers usually burn residues because they believe that it has advantageous effects on crop yields [26][27]. Many studies proposed that burning rice residues have positive as well as negative effects on the soil quality. Burning increases the availability of phosphorous and potassium nutrients for short time [28]. According to [29] burning rice residues in the field enhance the crop productivity for the next crop season. Some researchers have found negative effects of residues burning such as [30] and [31], according to them burning causes loss of plant nutrients such as nitrogen, potash and sulphur and microbial population and organic carbon is reduced. On the other hand, some practices alternative to burning of crop residues such as (1) recycling of residue in the soil through incorporation, surface retention to improve soil's physio-chemical and biological properties [32]. (2) Animal feed [36], (3) mushroom cultivation or bioenergy production [34]. (4) For cooking and lighting purpose [35]. Burning RS has many negative impacts, producing smoke, gaseous and particulate emissions (PM 10, PM 2.5, NOx, SO_2) in the atmosphere which ultimately affects health of population and climate [36][37].

Fig. 3. Open field burning of rice straw [38]

Fig. 4. Rice husk used in brick manufacturing industries [40]

RH is supplied to brick manufacturing industries where it is being burned, which causes release of CO_2 and methane into atmosphere which takes part in greenhouse effect and poor air quality. The amount of CO_2 released from burning depends upon the amount of RH burned and its carbon fraction [39].

The burning of rice residues has also adverse environmental impacts in terms of air pollution and climate change. Incomplete combustion of agricultural residues produces emissions of toxic air pollutants and greenhouse gases, black carbon which is a second largest source of global warming contribution after carbon dioxide. It captures radiations and warms the atmosphere and ultimately enhances glacier melting [26][41][24].

RH generated in the mill is partly used for heating purposes. Surplus amount of RH is supplied to brick manufacturing industries. RH is also agricultural waste generated after paddy rice milling. It is often used as fuel for green technology. RH is used in boilers to produce steams, in brick kilns to fire clay bricks, in boilers for rice processing industry, where RH have gone through self-burning process [42].

Limited studies have been conducted in Pakistan for the estimation of rice residues without taken into account the variation of residual characteristics such as residue to crop product ratio, lower heating values, availability factor and relative moisture content.

There have been many studies related to the utilization of rice residues as energy source. [1] Estimated that 17.86 million tons of RS from the rice crop are produced. [43] concluded that RH based electricity generation is more economically and environmentally viable compared to coal-based electricity generation. [44] estimated that RS and husk generated in the Punjab province of India contributed 33.43% of total residue potential. [45] have estimated that Bangladesh produces enormous amount of rice residues such as RS and husk. The available energy potential from rice residues was estimated to be 425.324 PJ during the year 2015-16. [39] estimated that annually 1328 GWh electricity can be generated from the available quantity of RH in Pakistan and 36,042 tons of CO_2 equivalent (tCO_2-eq) per year of methane can be avoided by utilizing RH instead of conventional fossil fuels. [46] have studied biomass residues as potential energy source of electricity generation in Punjab province of Pakistan. It is concluded that lot of potential is available to generate electricity of 1700 MW. [47] studied that the open field burning of RS release CO_2 and methane which contributes global warming. They have concluded that RS can be utilized for electricity generation through efficient conversion technologies. [48] have estimated that total residue potential from arable field crops and horticulture crops were 59.432 million tons, and 15.652 million tons, respectively. The available energy potential from arable field crops was 298,955 TJ and from horticultural crops was 65,491 TJ. [49] studied the resource potential of agricultural and animals waste for the generation of electricity and greenhouse gases mitigation potential. It was estimated that annual potential of 62,808 GWh from the total waste can be generated which accounts 27% of the total electricity consumption in the country. Moreover, the mitigation of greenhouse gases emissions from the biomass wasted based electricity generation were about 4,096 thousand t CO_2 per year. [50] studied agricultural crop residues as renewable energy source in Pakistan. A model based on MATLAB was developed to estimate the existing and future accessibility of the selected biomass residues as an energy source. They have estimated that 11000 MW electricity can be produced from the selected crop residues. Forecast shows that the plant capacity can be increased up to 16,000 MW by the year 2035. [51] studied the availability of RH for the generation of electricity in Bangladesh. They have proposed that RH is a viable option for the electricity generation in the country. [52] conducted experimental work on the open field burning of RS. They have found that the percentage of CO_2, CO, and NO_x to the total emissions were 15.3%, 13.9%, and 31.4% respectively.

The purpose of this study was to assess the potential of rice residues as an energy source and to estimate the gaseous pollutant emissions like CO, CO_2, NO, NO_2, NOx, and SO_2 caused by open field burning of rice residues. In this study we have estimated the potential of rice residues as dry mass, theoretical and available energy potential by taking into account the residual characteristics from the previous studies conducted in South Asian countries such as Pakistan, India, Bangladesh, Sri Lanka, and Afghanistan and limit values have been estimated.

2 Methodology

In order to estimate the residue potential, the first stage is to get primary input data relevant to rice crop production for the estimation of amount of available residue and energy potential from the crop residues. In the next step, biomass crop residues such as RS and RH is estimated from the annual crop production by considering residue to crop product ratio (RPR) and moisture level (M).

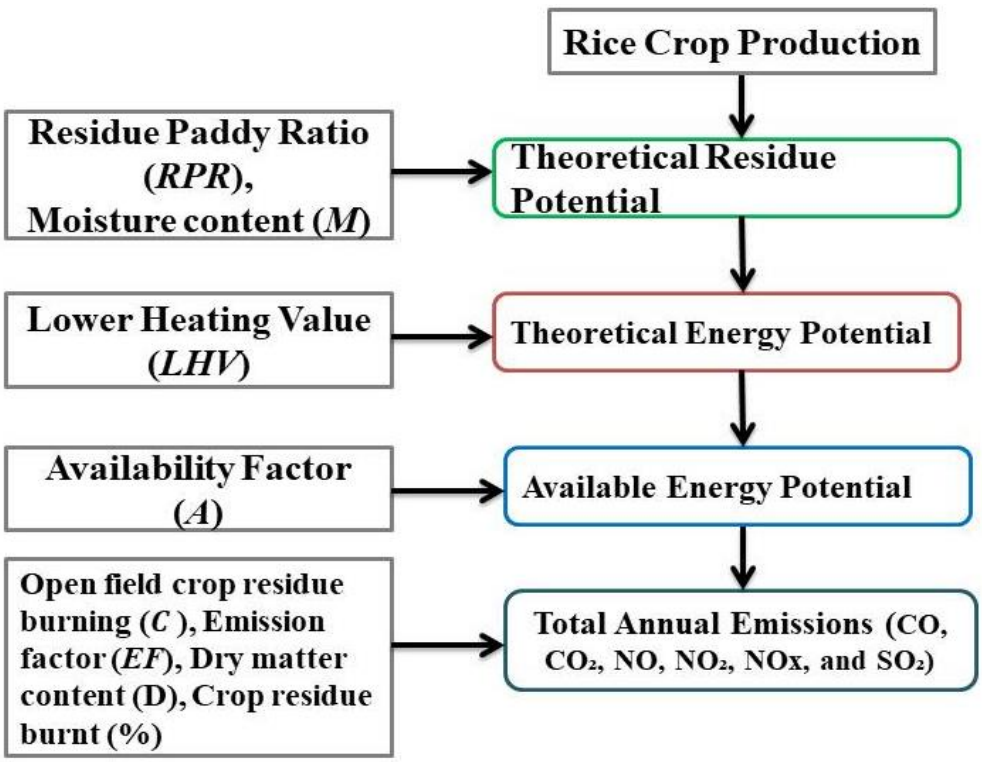

Fig. 5. Flow diagram for assessing the energy and emissions reduction potential from rice residues

The energy potential from the crop residue can be estimated by considering energy content value and availability factor of the particular residue. The amount of emissions from open field burning of residues is estimated by considering open field burning of the particular residue, emissions factors of particular gaseous pollutants and dry matter content. The methodology flow diagram is presented in the Fig. 5.

2.1 Rice Crop Production

According to Pakistan Economic Survey Report 2020, rice crop area was increased by 8% to 3.034 million hectares during 2019-20, therefore, the production increased by 2.9% to

7.410 million tons compared to previous year 2018-19. Paddy rice production data in Pakistan from 2012-13 to 2019-20 is taken from Pakistan Economic survey reports [4][54] and is presented in Table 1.

TABLE I. PADDY RICE PRODUCTION IN PAKISTAN [4]

Year	Potential of Paddy (Thousand Tons)
2012-13	5536
2013-14	6798
2014-15	7003
2015-16	6801
2016-17	6849
2017-18	7450
2018-19	7202
2019-20	7410
Average	**6881**

For the estimation of energy potential and gaseous pollutant emissions, the average value of the crop production was 6881 thousand tons which is considered as input data in order to reduce the yearly crop yield fluctuations.

2.2 Characterization of Rice Crop Residues

The evaluation of biomass characteristics is an important step for the assessment of energy potential through the conversion process prior to it utilization. The properties of biomass change rapidly with certain factors such as climatic conditions and seasonal variations which affect the thermal decomposition behavior, the product yield and quality [55]. Literature shows that there is considerable difference in characteristics and quantity of the crop residues depends upon many factors such as local climate conditions, difference in agricultural practices, crop production, crop type and varies from region to region [46][48][50][56]. Hence, the residual characteristics of biomass vary region to region. In this study, residual characteristics like residue crop production ratio (RPR), moisture level (M) and lower heating value (LHV) of dry biomass residues were taken into account from different studies in South Asian countries such as Pakistan, India, Bangladesh, Sri Lanka, and Afghanistan. The average values of residual properties were considered in order to reduce fluctuations in the data and results. The energy potential of rice residues was estimated by considering RPR, M, and LHV of dry matter of residues.

Moisture level plays a pivotal role in selection of biomass to energy conversion process [57]. M content indicates the presence of water in biomass and is an important factor for conversion of biomass feedstock to energy. High M decreases the heating value of the feedstock due to mass of water [19]. Therefore, the energy intensive drying process is required to reduce the M according to the conversion technology [58]. Residual characteristics values of rice straw and husk are presented in Table 3 and 4 respectively. It can be observed in the Table 3 and 4 that amount of residues generated from the crop production varies from region to region. For example, from Table 3, residue to crop ratio of RS ranges from 1 to 1.76 in different countries. The RPR of rice straw in Pakistan was given as 1. 1.5, 1.54, and 1.757. but these values were different for Bangladesh as 1.695 and 1.76. for India and Afghansitan it was close to Pakistan that is 1.5, for Sri Lanka it was 1.76. moisture content values of rice straw in these countries were near to each other and varies from 7.43 to 12.7%. however lower heating values of moisture varied from 12.81 to 18.74 MJ/kg. there were, 13.8, 17, and 18.74 MJ/kg for Pakistan. For India it was 15.03 and 15.54 MJ/kg, for Afghanistan it was 12.81 MJ/kg, for Sri Lanka, it was 16 MJ/kg, and for Bangladesh it was 16.3 MJ/kg.

TABLE II. ELEMENTAL ANALYSIS OF RICE RESIDUES [39][56]

Composition (%)	Rice straw (RS)	Rice husk (RH)
Carbon	28.55	44.13
Hydrogen	3.98	5.01
Nitrogen	1.15	0.39
Sulphur	0.61	0.07
Oxygen	65.71	50.40

TABLE III. CHARACTERISTICS OF RICE STRAW

Characteristics	Rice Straw	Country Reference
Residue Crop Ratio, (*RPR*)	(1-1.76)	Pakistan-[18][50][46][59][60][61] India-[62][44][22] Afghanistan- [20][63]. Sri Lanka-[64] Bangladesh-[21][45][65].
Lower Heating Value, (*LHV*) (MJ/kg)	(12.81-18.74)	Pakistan-[50] [46] [60] [56]. India- [66] [62][44]. Afghanistan-[20]. Sri Lanka-[64]. Bangladesh- [21] [45].
Moisture content, (*M*) (%)	(7.43-12.7)	Pakistan-[59] [56]. Afghanistan-[20]. Sri Lanka-[64]. Bangladesh-[21]. India-[66].

2.3 Theoretical Residues Potential

Theoretical rice residues (RH and RS) potential indicates the amount of residue j generated per year from the rice crop production. The amount of residues generated depends upon annual crop production, ratio of residue to crop product (RPR), and moisture level (M). Theoretical amount of residue j is estimated from the equation (1) by taking relevant data from Table 3, and 4.

$$TRP_j = Cp \times RPR_j \times [\frac{100-Mj}{100}] \qquad (1)$$

Where, Cp is the annual amount of the crop production in thousand tons, RPR is the residue j to crop production ratio. Thus, RPR=1 indicates that, 1 ton of the crop residue is produced from the 1 tons of crop production. M indicates the relative moisture content (%) of residue j.

Amount of residue generated depends upon the crop varieties, environmental factors region and agricultural practices of the concerned region. For example, RPR becomes 1.75 when the rice crop is harvested at 5cm above the ground level. RPR could decrease to 0.45, if the crop is cut by more than 5 cm above the ground [28][44]. The eight years average data related to the rice crop production from 2012-13 to 2019-20 is taken from Pakistan Economic Survey reports in 2018-19 and 2019-20 in order to reduce crop yield fluctuations per year.

TABLE IV. CHARACTERISTICS OF RICE HUSK

Characteristics	Rice Husk	Country Reference
Residue Crop Ratio, (*RPR*)	(0.20-0.321)	Pakistan- [18][50][46][59][60][61][39] India-[62][44][22] Afghanistan-[20][63]. Sri Lanka-[64] Bangladesh-[21][45] [65].
Lower Heating Value, (*LHV*) (MJ/kg)	(13.48 -17)	Pakistan-[50] [46] [60] [56]. India-[66] [62] [44]. Afghanistan-[20]. Sri Lanka-[64]. Bangladesh- [45].
Moisture content, (*M*) (%)	(7.88-12.4)	Pakistan-[59] [56] [39]. Afghanistan-[20]. Sri Lanka-[64]. Bangladesh-[21]. India-[66].

2.4 Theoretical Energy Potential

The theoretical or ideal energy potential represents the total amount of energy potential from the generated dry biomass residues and can be estimated by the following equation (2).

$$TEP_j = TRP_j \times LHV_j \qquad (2)$$

Where, LHV indicates lower heating value (MJ/kg) of particular residue j

2.5 Available Energy Potential

The available energy potential indicates the amount of energy that can be technically and economically generated from the crop residues. Its value depends upon certain factors such as collection mechanism, characteristics of biomass and the conversion technology [44]. The theoretical energy potential is constraints by alternative uses of crop residues and agricultural practices of particular region [44]. Therefore, availability factor is incorporated in the following equation to estimate the available energy potential from the crop residues.

$AEP_j = TEP_j \times A_j$ (3)

Where A is the availability of the residue j, which is 0.6 for RS and 0.8 for RH [45].

TABLE V. RESIDUE PRODUCT RATIO, LHV, AND MOISTURE, OF RICE CROP RESIDUES.

	Rice Straw		Rice Husk	
	Range	Mean	Range	Mean
RPR	1-1.76	1.38	0.20-0.321	0.26
M (%)	7.43-12.7	10.065	7.88-12.4	10.14
LHV) (MJ/kg)	12.81-18.74	15.775	13.48-17	15.24

2.6 Estimation of total annual gases Emissions

In order investigate/estimate the amount of gaseous emissions such as (CO, CO_2, NO, NO_2, NOx, and SO_2) caused by open field burning of rice RS and RH. The total amount of gaseous pollutant emissions can be estimated by the following Eq. (4).

$$E_{i,j} = C_j \times EF_{i,j} \quad (4)$$

Where, E is total annual emissions (Gg) from the pollutant i emitted from the crop residue j. EF is the specific emission factor (g/kg) of pollutant i from burning of the residue j, and C is the total amount (kg) of burnt crop residue j.

2.6.1 Estimation of crop residues burnt

The crop residues burned in the field depends upon the amount of crop production, dry matter content, portion of the residue burned. The total amount of the crop residue burnt can be estimated by the following Eq. (5).

$$C_j = Cp \times RPR_j \times D_j \times \emptyset_j \quad (5)$$

Where, TRP is theoretical biomass potential (Thousand tons) of the residue j, $\emptyset$ is Crop residue j burnt (%) and D is dry matter content of residue j. Dry matter content for RH and straw is taken from [67] and proportion of burnt residue (%) is taken as 25% as estimated by [68].

2.6.2 Emission Factors

Emission factors are used to estimate and quantify the pollutant emissions from burning of biomass residues vary with time, space and largely depend upon type, quality and biomass fuel composition and climate and burning condition and onsite experiments such as indoor and in-field [69][24]. The mean values of emission factors of different gaseous pollutants from the open field burning of rice residues as estimated by [24] have presented in the Table 6.

TABLE VI. EMISSIONS FACTORS (EF) (G/KG) FOR GASEOUS POLLUTANTS [24].

Rice Residues	Rice Straw	Rice Husk
CO_2	1090.1	880.48
CO	17.19	14.05
NO	1.48	1.38
NO_2	0.89	0.19
NOx	3.16	2.31
SO_2	0.38	0.11

3 Results and Discussion

The theoretical crop residues potential from RS and RH, the theoretical and available energy potential and total emissions of gaseous pollutants is estimated from RS and RH.

3.1 Total Amount of Residues and Energy Potential

The mean value eight years from 2012 to 2020 of rice crop production is taken as 6881 thousand tons in order to reduce yearly crop yield fluctuations. The total amount of rice residues obtained as dry substance and is estimated as 10,147.65 thousand tons. The amount of RS produced is 8,540 thousand tons while the amount of RH generated is 1607.65 thousand tons of dry mass. Theoretical energy potential was estimated as 159,219 TJ out of which 134,718.5 TJ was estimated from RS and 24,500.586 TJ from RH.

The limit values of rice crop residues characteristics were considered, and maximum, minimum and average potential values were estimated as presented in Table 5. The residual properties of rice residues (residue crop ratio, lower heating value, and relative moisture content) values vary among the countries as shown in Table 3 and 4. Therefore, the estimated potential values from crop residues change within the limits. The location of the crop and its characteristics such as crop production and agricultural practices also affect the quantity of residues generated. As shown in Fig. 6, when estimating the energy potential of RS, the energy potential of 81,600 TJ was obtained when the minimum values of properties such as ratio of residue to product, moisture level, and lower heating values were taken. Similarly, energy values of 134,718.5 TJ and 198,129 TJ from RS were obtained when average and maximum limit values were considered respectively.

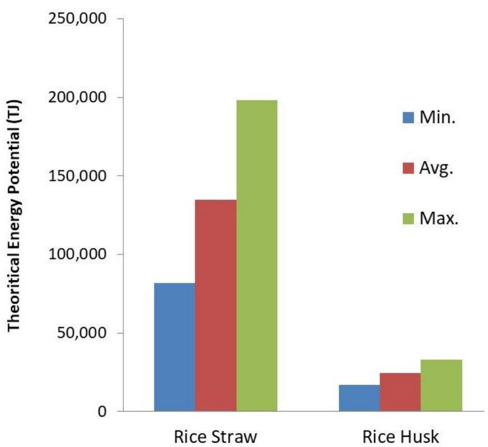

Fig. 6. Comparison of TEP of rice residues

Fig. 7 shows total theoretical and available estimated potential from the crop residues in Pakistan. Potential values were estimated as minimum, maximum and average of residual characteristics. The total theoretical energy potential of the rice residues obtained from the rice crop production has minimum 98,692.64 TJ, an average 159,219 TJ, and maximum of 231,024 TJ. While the total available energy potential obtained from the rice residues were estimated as minimum 62,634 TJ, an average 100,431 TJ, and maximum value of 145,193 TJ.

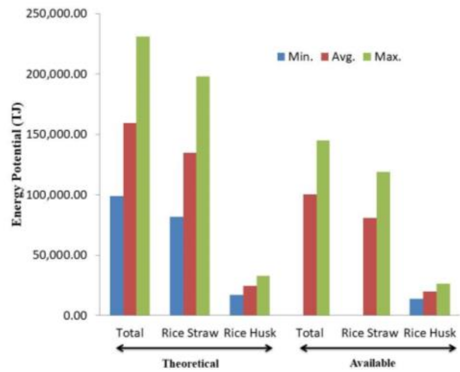

Fig. 7. Total Theoretical and Available Energy Potential of Rice residues

3.2 Estimation of gaseous Emissions

The amount of gaseous pollutants such as CO, CO_2, NO, NO_2, NOx, and SO_2 emissions (Gg) from the rice residues open field burning are estimated by considering the proportion of residue burn, dry matter content, and specific emission factors of gaseous pollutants. Based on dry matter fraction and proportion of burnt crop residue, the total amount of burnt crop residue for RS and RH was 2017.85 thousand tons and 380 thousand tons respectively as presented in the Table 7. The amount of crop residue such as RS burnt is more than the RH. Because the yield value of RS is more.

TABLE VII. AMOUNT OF BURNT RESIDUES IN PAKISTAN

Rice Residues	Rice Straw	Rice Husk
RPR	1.38	0.26
Amount of Crop residue (Th. Tons)	9495.78	1789
Dry matter content [70]	0.85	0.85

Crop residue/dry matter burnt (%) [68]	25	25
Amount of Burnt Residue, C_j (Th. Tons)	2017.85	380

Total amount of pollutant emissions (Gg) from rice residues for CO_2, CO, NO_2, NO, NOx, and SO_2 are presented in Fig. 10. Total pollutant emissions from rice residues were 2534.58, 40.025, 3.51, 1.868, 7.254, and 0.808 Gg for CO_2, CO, NO, NO_2, NOx, and SO_2 respectively. Total pollutant emissions from burning of RS were 2200 Gg for CO_2, 34.686 Gg for CO, 2.986 Gg for NO, 1.796 Gg for NO_2, 6.376 Gg for NOx, and 0.766 Gg for SO_2. It can be observed from the Fig. 8 that the gaseous pollutants emissions from the burning of RS is more than the RH because of emissions factors of RS is higher than rice husk.

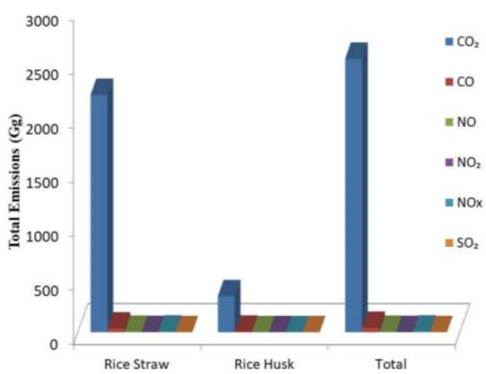

Fig. 8. Emissions from Rice straw and Rice husk

4 Conclusion

This study focuses on the exploitation of rice crop residues as an energy source and assessment of gaseous pollutants emissions caused by open field burning. The average amount of rice residues is estimated to be 10147.65 thousand tons that can be efficiently utilized to produce 159219 TJ of energy which is approximately 3803 kilo tons of oil equivalent (ktoe). If this amount of residues is properly utilized for electricity generation, 44,229 GWh can be produced annually. The available energy potential is estimated as 100,431TJ. This available energy potential is 2398.75 ktoe. If the available amount of residues is efficiently utilized for electricity generation, an annual amount of 27,897GWh electricity could be produced. Total emissions from burning of rice residues were 1749.59, 27.639, 2.432, 1.265, 4.997, and 0.549 Gg for CO_2, CO, NO, NO_2, NOx, and SO_2 respectively. Hence it is concluded that the crop residues generated in Pakistan can be effectively utilized as an alternative energy source, to reduce the demand supply gap, reduce reliance on fossil fuels and prevent environmental degradation.

5 Recommendations

There are certain issues related to utilization of crop residues as an energy source such as residues availability, agricultural practices, and unawareness about the efficient utilization of residues as alternative source of energy. Therefore, the Government of Pakistan should institute and implement proper policies and regulations among the public and private sectors to encourage renewable energy technologies by providing subsidies, incentives and reducing taxes, and creating awareness among the farmers about the utilization of crop residues as an alternative energy source.

REFERENCES

[1] M. Irfan et al., "Assessing the energy dynamics of Pakistan: Prospects of biomass energy," Energy Reports, vol. 6, pp. 80–93, 2020, doi: 10.1016/j.egyr.2019.11.161.

[2] K. R. Abbasi, M. Shahbaz, Z. Jiao, and M. Tufail, "How energy consumption, industrial growth, urbanization, and CO2 emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach," Energy, vol. 221, p. 119793, 2021, doi: 10.1016/j.energy.2021.119793.

[3] M. O. Chaudhry, M. Z. Faridi, and S. Riaz, "Energy Crisis and Macroeconomic Stability in Pakistan.," Pakistan J. Soc. Sci., vol. 35, no. 1, pp. 425–436, 2015.

[4] G. of P. Finance Division, Pakistan Economic Survey Report 2019-20. .

[5] T. Iqbal et al., "Sketching Pakistan's energy dynamics: Prospects of biomass energy," J. Renew. Sustain. Energy, vol. 10, no. 2, 2018, doi: 10.1063/1.5010393.

[6] N. Hossain, M. A. Bhuiyan, B. K. Pramanik, S. Nizamuddin, and G. Griffin, "Waste materials for wastewater treatment and waste adsorbents for biofuel and cement supplement applications: A critical review," J. Clean. Prod., vol. 255, 2020, doi: 10.1016/j.jclepro.2020.120261.

[7] K. Harijan, M. A. Uqaili, M. Memon, and U. K. Mirza, "Forecasting the diffusion of wind power in Pakistan," Energy, vol. 36, no. 10, pp. 6068–6073, 2011, doi: 10.1016/j.energy.2011.08.009.

[8] H. Zhang et al., "A laboratory study of agricultural crop residue combustion in China: Emission factors and emission inventory," Atmos. Environ., vol. 42, no. 36, pp. 8432–8441, 2008, doi: 10.1016/j.atmosenv.2008.08.015.

[9] N. Abas, A. Kalair, N. Khan, and A. R. Kalair, "Review of GHG emissions in Pakistan compared to SAARC countries," Renew. Sustain. Energy Rev., vol. 80, no. January 2016, pp. 990–1016, 2017, doi: 10.1016/j.rser.2017.04.022.

[10] M. M. Rahman and J. V. Paatero, "A methodological approach for assessing potential of sustainable agricultural residues for electricity generation: South Asian perspective," Biomass and Bioenergy, vol. 47, no. 0, pp. 153–163, 2012, doi: 10.1016/j.biombioe.2012.09.046.

[11] N. A. Khan and H. el Dessouky, "Prospect of biodiesel in Pakistan," Renew. Sustain. Energy Rev., vol. 13, no. 6–7, pp. 1576–1583, 2009, doi: 10.1016/j.rser.2008.09.016.

[12] M. M. Rafique and H. M. S. Bahaidarah, "Thermo-economic and environmental feasibility of a solar power plant as a renewable and green source of electrification," Int. J. Green Energy, vol. 16, no. 15, pp. 1577–1590, 2019, doi: 10.1080/15435075.2019.1677237.

[13] H. Yaqoob et al., "Feasibility Study of a 50 MW wind farm project in Pakistan," J. Adv. Res. Fluid Mech. Therm. Sci., vol. 74, no. 2, pp. 27–42, 2020, doi: 10.37934/ARFMTS.74.2.2742.

[14] H. Yaqoob et al., "Case Studies in Chemical and Environmental Engineering Energy evaluation and environmental impact assessment of transportation fuels in Pakistan," Case Stud. Chem. Environ. Eng., vol. 3, no. December 2020, p. 100081, 2021, doi: 10.1016/j.cscee.2021.100081.

[15] G. of P. Finance Division, Pakistan Economic Survey 2017-18. 2019.

[16] L. A. Silva, I. F. S. dos Santos, G. de O. Machado, G. L. Tiago Filho, and R. M. Barros, "Rice husk energy production in Brazil: An economic and energy extensive analysis," J. Clean. Prod., vol. 290, p. 125188, 2020, doi: 10.1016/j.jclepro.2020.125188.

[17] K. Ahmed, S. Shahid, and N. Nawaz, "Impacts of climate variability and change on seasonal drought characteristics of Pakistan," Atmos. Res., vol. 214, no. August, pp. 364–374, 2018, doi: 10.1016/j.atmosres.2018.08.020.

[18] A. W. Bhutto, A. A. Bazmi, and G. Zahedi, "Greener energy: Issues and challenges for Pakistan - Biomass energy prospective," Renew. Sustain. Energy Rev., vol. 15, no. 6, pp. 3207–3219, 2011, doi: 10.1016/j.rser.2011.04.015.

[19] A. Abdullah et al., "Bioenergy potential and thermochemical characterization of lignocellulosic biomass residues available in Pakistan," vol. 37, no. 2, pp. 1–8, 2020, doi: 10.1007/s11814-020-0624-0.

[20] A. G. Noori, P. A. Salam, and A. M. Fazli, "Assessment of Selected Biomass Energy Potential in Afghanistan," vol. 4, no. 6, pp. 6–14, 2019.

[21] A. S. N. Huda, S. Mekhilef, and A. Ahsan, "Biomass energy in Bangladesh : Current status and prospects," Renew. Sustain. Energy Rev., vol. 30, pp. 504–517, 2014, doi: 10.1016/j.rser.2013.10.028.

[22] M. Hiloidhari and D. C. Baruah, "Rice straw residue biomass potential for decentralized electricity generation: A GIS based study in Lakhimpur district of Assam, India," Energy Sustain. Dev., vol. 15, no. 3, pp. 214–222, 2011, doi: 10.1016/j.esd.2011.05.004.

[23] R. Azhar, M. Zeeshan, and K. Fatima, "Crop residue open fi eld burning in Pakistan ; multi-year high spatial resolution emission inventory for 2000 – 2014," Atmos. Environ., vol. 208, no. September 2018, pp. 20–33, 2019, doi: 10.1016/j.atmosenv.2019.03.031.

[24] M. Irfan et al., "Estimation and characterization of gaseous pollutant emissions from agricultural crop residue combustion in industrial and household sectors of Pakistan," Atmos. Environ., vol. 84, pp. 189–197, 2014, doi: 10.1016/j.atmosenv.2013.11.046.

[25] G. CAO, X. ZHANG, S. GONG, and F. ZHENG, "Investigation on emission factors of particulate matter and gaseous pollutants from crop residue burning," J. Environ. Sci., vol. 20, no. 1, pp. 50–55, 2008, doi: 10.1016/S1001-0742(08)60007-8.

[26] T. Ahmed, B. Ahmad, and W. Ahmad, "Why do farmers burn rice residue? Examining farmers' choices in Punjab, Pakistan," Land use policy, vol. 47, pp. 448–458, 2015, doi: 10.1016/j.landusepol.2015.05.004.

[27] A. Junpen, J. Pansuk, O. Kamnoet, and P. Cheewaphongphan, "Emission of Air Pollutants from Rice Residue Open," 2018, doi: 10.3390/atmos9110449.

[28] O. Erenstein, "Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological

implications," Soil Tillage Res., vol. 67, no. 2, pp. 115–133, 2002, doi: 10.1016/S0167-1987(02)00062-4.

[29] M. Haider, Published by the South Asian Network for Development and Environmental Economics (SANDEE) PO Box 8975, EPC 1056, Kathmandu, Nepal. Tel: 977-1-, no. 71. 2012.

[30] P. K. Gupta et al., "Residue burning in rice-wheat cropping system: Causes and implications," Curr. Sci., vol. 87, no. 12, pp. 1713–1717, 2004.

[31] B. J. Heard, C. Cavers, and G. Adrian, "Up in Smoke—- Nutrient Loss with Straw Burning," Better Crop., vol. 90, no. 3, pp. 10–11, 2006.

[32] K. G. Mandal, A. K. Misra, K. M. Hati, K. K. Bandyopadhyay, and P. K. Ghosh, "Rice residue-management options and effects on soil properties and crop productivity," vol. 2, no. January, pp. 224–231, 2004.

[33] R. Article, S. Devi, C. Gupta, S. L. Jat, and M. S. Parmar, "Crop residue recycling for economic and environmental sustainability : The case of India," pp. 486–494, 2017.

[34] C. Román-Figueroa, N. Montenegro, and M. Paneque, "Bioenergy potential from crop residue biomass in Araucania Region of Chile," Renew. Energy, vol. 102, pp. 170–177, 2017, doi: 10.1016/j.renene.2016.10.013.

[35] A. Vatsanidou, C. Kavalaris, S. Fountas, N. Katsoulas, and T. Gemtos, "A life cycle assessment of biomass production from energy crops in crop rotation using different tillage system," Sustain., vol. 12, no. 17, 2020, doi: 10.3390/SU12176978.

[36] I. Kumar, V. Bandaru, S. Yampracha, L. Sun, and B. Fungtammasan, "Limiting rice and sugarcane residue burning in Thailand: Current status, challenges and strategies," J. Environ. Manage., vol. 276, no. January, p. 111228, 2020, doi: 10.1016/j.jenvman.2020.111228.

[37] M. Z. Haider, "Determinants of rice residue burning in the field," J. Environ. Manage., vol. 128, pp. 15–21, 2013, doi: 10.1016/j.jenvman.2013.04.046.

[38] C. Menke, S. Garivait, and B. Gadde, "Air pollutant emissions from rice straw open field burning in India , Thailand and the Philippines," Environ. Pollut., vol. 157, no. 5, pp. 1554–1558, 2009, doi: 10.1016/j.envpol.2009.01.004.

[39] O. Mohiuddin, A. Mohiuddin, M. Obaidullah, H. Ahmed, and S. Asumadu-Sarkodie, "Electricity production potential and social benefits from rice husk, a case study in Pakistan," Cogent Eng., vol. 3, no. 1, 2016, doi: 10.1080/23311916.2016.1177156.

[40] P. Ahmed Ali SOhu (Quaid-e-Awam University of Engineering, Science and Technology Nawabshah, Sindh, "Study and Analysis of the potential of Rice Husk (biomass) as a viable source of Energy in Larkano and Kamber Shahdadkot districts of Sindh."

[41] P. Forster et al., "Bounding the role of black carbon in the climate system : A Scientific assessment Bounding the role of black carbon in the climate system : A scienti fi c assessment," no. November 2017, 2013, doi: 10.1002/jgrd.50171.

[42] G. H. M. J. S. De Silva, S. Vishvalingam, and T. Etampawala, "Effect of waste rice husk ash from rice husk fuelled brick kilns on strength , durability and thermal performances of mortar," Constr. Build. Mater., vol. 268, p. 121794, 2021, doi: 10.1016/j.conbuildmat.2020.121794.

[43] L. Q. Luu and A. Halog, "Rice Husk Based Bioelectricity vs. Coal-fired Electricity: Life Cycle Sustainability Assessment Case Study in Vietnam," Procedia CIRP, vol. 40, pp. 73–78, 2016, doi: 10.1016/j.procir.2016.01.058.

[44] J. Singh, "Overview of electric power potential of surplus agricultural biomass from economic, social, environmental and technical perspective - A case study of Punjab," Renew. Sustain. Energy Rev., vol. 42, pp. 286–297, 2015, doi: 10.1016/j.rser.2014.10.015.

[45] M. A. Salam, K. Ahmed, N. Akter, and T. Hossain, "ScienceDirect A review of hydrogen production via biomass gasification and its prospect in Bangladesh," Int. J. Hydrogen Energy, vol. 43, no. 32, pp. 14944–14973, 2018, doi: 10.1016/j.ijhydene.2018.06.043.

[46] M. Uzair, S. S. Sohail, N. U. Shaikh, and A. Shan, "Agricultural residue as an alternate energy source: A case study of Punjab province, Pakistan," Renew. Energy, vol. 162, pp. 2066–2074, 2020, doi: 10.1016/j.renene.2020.10.041.

[47] J. Logeswaran, A. H. Shamsuddin, A. S. Silitonga, and T. M. I. Mahlia, "Prospect of using rice straw for power generation: a review," Environ. Sci. Pollut. Res., vol. 27, no. 21, pp. 25956–25969, 2020, doi: 10.1007/s11356-020-09102-7.

[48] A. O. Avcıoğlu, M. A. Dayıoğlu, and U. Türker, "Assessment of the energy potential of agricultural biomass residues in Turkey," Renew. Energy, vol. 138, pp. 610–619, 2019, doi: 10.1016/j.renene.2019.01.053.

[49] S. M. Safieddin Ardebili, "Green electricity generation potential from biogas produced by anaerobic digestion of farm animal waste and agriculture residues in Iran," Renew. Energy, vol. 154, pp. 29–37, Jul. 2020, doi: 10.1016/j.renene.2020.02.102.

[50] M. Kashif et al., "Untapped renewable energy potential of crop residues in Pakistan: Challenges and future directions," J. Environ. Manage., vol. 256, no. September 2019, p. 109924, 2020, doi: 10.1016/j.jenvman.2019.109924.

[51] M. R. Abedin and H. S. Das, "Electricity from rice husk: A potential way to electrify rural Bangladesh," Int. J. Renew. Energy Res., vol. 4, no. 3, pp. 604–609, 2014, doi: 10.20508/ijrer.15831.

[52] H. Zhang et al., "A laboratory study of agricultural crop residue combustion in China: Emission factors and emission inventory," Atmos. Environ., vol. 42,

no. 36, pp. 8432–8441, Nov. 2008, doi: 10.1016/j.atmosenv.2008.08.015.

[53] M. Adnan, J. Ahmad, S. Farooq, and M. Imran, "A techno-economic analysis for power generation through wind energy : A case study of Pakistan," Energy Reports, vol. 7, pp. 1424–1443, 2021, doi: 10.1016/j.egyr.2021.02.068.

[54] G. of P. Finance Division, Pakistan Economic Survey Report 2018-19. 2020.

[55] A. Ahmed, S. Hidayat, M. S. Abu Bakar, A. K. Azad, R. S. Sukri, and N. Phusunti, "Thermochemical characterisation of Acacia auriculiformis tree parts via proximate, ultimate, TGA, DTG, calorific value and FTIR spectroscopy analyses to evaluate their potential as a biofuel resource," Biofuels, vol. 12, no. 1, pp. 9–20, 2021, doi: 10.1080/17597269.2018.1442663.

[56] A. Abdullah et al., "Potential for sustainable utilisation of agricultural residues for bioenergy production in Pakistan: An overview," J. Clean. Prod., vol. 287, p. 125047, 2021, doi: 10.1016/j.jclepro.2020.125047.

[57] S. Reza, A. Ahmed, W. Caesarendra, and M. S. A. Bakar, "Acacia Holosericea : An Invasive Species for Bio-char , Bio-oil , and Biogas Acacia Holosericea : An Invasive Species for Bio-char , Bio-oil , and Biogas Production," no. April, 2019, doi: 10.3390/bioengineering6020033.

[58] M. Danish, M. Naqvi, U. Farooq, and S. Naqvi, "Characterization of South Asian agricultural residues for potential utilization in future ' energy mix ,'" Energy Procedia, vol. 75, pp. 2974–2980, 2015, doi: 10.1016/j.egypro.2015.07.604.

[59] U. U. Rehman Zia, T. ur Rashid, W. N. Awan, A. Hussain, and M. Ali, "Quantification and technological assessment of bioenergy generation through agricultural residues in Punjab (Pakistan)," Biomass and Bioenergy, vol. 139, no. July, p. 105612, 2020, doi: 10.1016/j.biombioe.2020.105612.

[60] S. Butt, I. Hartmann, and V. Lenz, "Bioenergy potential and consumption in Pakistan," Biomass and Bioenergy, vol. 58, pp. 379–389, 2013, doi: 10.1016/j.biombioe.2013.08.009.

[61] Eaz. husnain, "02-Agriculture finl," pp. 19–40, 2016, [Online]. Available: http://www.finance.gov.pk/survey/chapters_17/02-Agriculture.pdf.

[62] M. Hiloidhari, D. Das, and D. C. Baruah, "Bioenergy potential from crop residue biomass in India," Renew. Sustain. Energy Rev., vol. 32, pp. 504–512, 2014, doi: 10.1016/j.rser.2014.01.025.

[63] A. Milbrandt, R. Overend, A. Milbrandt, and R. Overend, "Assessment of Biomass Resources in Afghanistan Assessment of Biomass Resources in Afghanistan," no. January, 2011.

[64] K. K. C. K. Perera, P. G. Rathnasiri, S. A. S. Senarath, and A. G. T. Sugathapala, "Assessment of sustainable energy potential of non-plantation biomass resources in Sri Lanka," vol. 29, pp. 199–213, 2005, doi: 10.1016/j.biombioe.2005.03.008.

[65] A. K Hossain and O. Badr, "Prospects of renewable energy utilisation for electricity generation in Bangladesh," Renew. Sustain. Energy Rev., vol. 11, no. 8, pp. 1617–1649, 2007, doi: 10.1016/j.rser.2005.12.010.

[66] J. Singh, B. S. Panesar, and S. K. Sharma, "Energy potential through agricultural biomass using geographical information system-A case study of Punjab," Biomass and Bioenergy, vol. 32, no. 4, pp. 301–307, 2008, doi: 10.1016/j.biombioe.2007.10.003.

[67] D. G. Streets, K. F. Yarber, J. H. Woo, and G. R. Carmichael, "Biomass burning in Asia: Annual and seasonal estimates and atmospheric emissions," Global Biogeochem. Cycles, vol. 17, no. 4, 2003, doi: 10.1029/2003gb002040.

[68] M. M. Iqbal and A. M. Goheer, "Greenhouse gas emissions from agro-ecosystems and their contribution to environmental change in the Indus Basin of Pakistan," Adv. Atmos. Sci., vol. 25, no. 6, pp. 1043–1052, 2008, doi: 10.1007/s00376-008-1043-z.

[69] X. Zhang, Y. Lu, and X. Qian, "A high-resolution inventory of air pollutant emissions from crop residue burning in China," Atmos. Environ., vol. 213, no. September 2018, pp. 207–214, 2019, doi: 10.1016/j.atmosenv.2019.06.009.

[70] G. R. Carmichael, Biomass burning in Asia : Annual and seasonal estimates and atmospheric emissions Biomass burning in Asia : annual and seasonal estimates and atmospheric emissions, no. June. 2014.

Abbreviations

IEA, International Energy Agency; FY, Fiscal Year; RH, Rice Husk; RS, Rice Straw; M, Moisture Level; TEP, Theoretical Energy Potential; AEP, Available Energy Potential; LHV, Lower Heating Value; CO, Carbon mono oxide; CO_2, Carbon dioxide; NO, Nitrogen mono oxide; NO_2, Nitrogen di oxide; NOx, Nitrogen oxides; SOx, Sulphur oxides; GHG, Green House Gases; PM, Particulate matter; Mt CO_2-eq, Million tons CO_2 equivalent; EF, Emission Factor; toe, tons of oil equivalent; GWh, Gega Watt Hour; RPR, Residue to Crop Production Ratio; MJ, Mega Joule; TJ, Tera Joule; kg, kilo gram; Gg, Gega grams; USD, United States Dollar; GDP, Gross Domestic Product.