Arabian Journal of Geosciences (2023) 16:161
https://doi.org/10.1007/s12517-023-11247-x

ORIGINAL PAPER

Co-combustion of rice husk with Thar lignite coal and their effects on gaseous emissions for environmental friendly and sustainable energy production

Jawad Abdullah Butt[1] · Yasmin Nergis[1] · Ahmad Hussain[2] · Adnan Khan[3] · Mughal Sharif[1]

Received: 3 January 2022 / Accepted: 27 January 2023 / Published online: 10 February 2023

Abstract
Co-combustion of coal and biomass is a sustainable and cost-operative choice for generating power. Biomass assets such as rice husk play a vital part in decreasing the concentration of discharge gases, while usage in the co-combustion approach. This research concentrated on the physicochemical and emission investigation of coal and rice husk blends for emission reduction. Thar coal comprises higher content of moisture and sulfur while lower in volatile matter and ash. However, rice husk is higher in volatile matter, and lower in moisture and sulfur with higher ash. The blends of coal with rice husk in weight fractions 90:10 (CRh-1), 80:20 (CRh-2), and 70:30 (CRh-3) were also characterized. The study reveals that CRh-1 contains 1.39%, CRh-2 contains 1.17%, and CRh-3 contained 0.99% elemental sulfur respectively after the blend. Flue gases analysis from muffle furnace stack showed that coal-rice husk blends 70:30% (CRh-3) were found to be feasible from the energy production point of opinion. Overall, NOx and SOx discharges were found to decline from 89 ppm (CRh-1) to 34 ppm (CRh-3) and 828 ppm (CRh-1) to 169 ppm (CRh-3) respectively by increasing the blending fraction from 10 to 30%. The study has concluded that rice husk blending would be a beneficial choice to reduce SOx and NOx discharges in the combustion of Thar coal for efficient, sustainable, and environmentally friendly combustion for energy production and support to fulfill the requirement of UN Environment SDG 7 clean energy goal.

Keywords Thar lignite coal · Rice husk · Co-combustion · Characterization · Sustainable energy · Gaseous emission

Introduction

Energy acts as an important role in the economic, societal, and sustainable development of a country. In the present perspective, all over the world, fossil fuels bring about 80% of energy supplies (Sharma 2016). For several years, the fast escalation in the world populace has triggered the energy required to increase multiple folds, which has strained the conventional sources of energy all over the world (Nazar et al. 2021). Moreover, fossil fuel usage increases environmental problems such as climate change, air pollution, and discharge of greenhouse gases (Abdeshahian et al. 2016; Bariani et al. 2020). Current power production has a massive economic load on the state's budget due to the import of oil to sustain the current energy mix, and the condition is increased by the fast reduction of gas resources. The severe energy crisis also causes adversative economic and social impacts. This directly affected industrial, commercial, and population activities (Naseem et al. 2020). Sustainable energy production and distribution of power to meet the existing and forthcoming industrial and local requirements in Pakistan will depend on maximum production from the diverse energy assets to create major inputs to the supply chain (Ahmad et al. 2015; Raheem et al. 2016).

Pakistan is placed seven in positions of coal comprising country extending from sub-bituminous to brown lignite

Responsible Editor: Amjad Kallel

✉ Adnan Khan
adkhan@uok.edu.pk

[1] Environmental Research Center, Department of Earth and Environmental Science, Bahria University, Karachi Campus, 13-National Stadium Road Karachi, 75260 Karachi, Pakistan

[2] Department of Mechanical Engineering, DHA Suffa University, Karachi, Pakistan

[3] Department of Geology, University of Karachi, Karachi, Pakistan

coal (Malkani 2012). These assets contain around 185 billion tons; of that, 175 billion tons are situated in the Thar Desert of Sindh domain and are called Thar coal (Muneer and Asif 2007). Thar lignite coal can generate 100,000 MW of electricity every year for 200 years (EIU Report 2017). Biomass is a renewable and environmentally pleasant asset of energy that is mostly derivative from agronomic waste (Saini et al. 2015; Abaide et al. 2019). Biomass usage as an alternative energy asset has progressively gained attention because of its low cost and easy accessibility as a by-product (Shahbaz et al. 2020). Approximately 0.30 tons of biomass residue is annually generated in the country with an approximately energy capability of 166.72 TWh/year (Irfan et al. 2020).

All over the world, rice is the main crop that is made in rice husk through the rice milling practice in huge volume and comprises small contented of sulfur and other pollutants (Gautam et al. 2020). Rice husk comprises organic and inorganic substances. Paddy lands might come to be contaminated by the accumulation of numerous, i.e., fertilizers; releases from the rapidly spreading industrial lands; organic solid waste; and wastewater irrigation schemes (Akram et al. 2018). The use of biochar in the soil might play a vigorous part in decreasing the adversative effects of climate change and dangers to sustainable crop production (Tauqeer et al. 2022). Annually in the world, around 134 Mt of rice husk is formed and around 90% of residual is combusted outdoor or discarded into ponds and canals (Quispe et al. 2017). Due to its ease of transport and low cost, rice husk takes too much popularity as boiler fuel. Hence, rice husk is the most productive biomass asset in Pakistan (Hussain et al. 2015). Due to the constant escalation in oil prices, at present, the consumption of coal and other viable assets together with biomass as an energy source has revealed the potential for cost-effective and economic benefit (Xu 2013). Both coal and biomass are carbonaceous resources, created from floras and have similar major fundamental ingredients (Boerrigter and Rauch 2005). Coal blends are used for low-grade coals, to increase the coals ignition performance, attempt to enhance the flexibility of fuel type, and comply with the conditions of emission regulation (Arenillas, et al. 2004). Methods like combustion, gasification, and pyrolysis might be used to produce electricity from coal-biomass blends (Chieng and Kuan 2020). The combustion method is the utmost broadly used worldwide (Cardozo et al. 2016).

Co-combustion is an environmentally friendly practice for the use of low-grade coal to reduce CO_2 discharges and collaborate to decrease NOx and SOx pollution (Siddiqi et al. 2018). The blending proportion of biomass up to 10 to 30% is best for the decrease of precarious pollutants (Zhong et al. 2006). The blending proportion of around 40% of biomass drops the temperature and decreases energy efficacy by around 8% (Suksankraisorn et al. 2004). Furthermore, the addition of biomass for power creation in combination with coal might make the procedure further sustainable (Kanwal et al. 2021). The United Nations Environment Sustainable Development Goal (SDG 7) also confirms admittance to reasonable, consistent, sustainable, and modern energy for all. The environmental effects of energy schemes contain local, regional, and worldwide emission pollution from the burning of fuels, climate change, and effects on the veracity and stability of diverse environments. Limited literature is existing that explained the emission characteristic of a furnace, co-combustion with Thar lignite coal,and the utmost significance for the usage of rice husk as a blended fuel in a furnace with emission properties. Current research explores in detail the coal-rice husk blending effects on coal configuration and emission gases and also helps to find out new thermo-chemical characteristics data of Thar coal and rice husk to deliver the solution of energy shortage by an operative and effective consumption of Thar coal reserves.

The study objective is to inspect the physicochemical characteristic of low-grade Thar lignite coal and their blends of rice husk biomass for burning. Characterization of coal and rice husk and their blends in several mixtures such as 90:10, 80:20, and 70:30 (Coal: RH) by weight % was correspondingly investigated and also to find out the influence of these combination proportions on discharge gases such as NOx, SO_2, CO, and CO_2. This work shows a significant part in saving our natural assets and meeting industrial energy supplies. This investigation is a guideline for co-firing of Thar coal and rice husk efficiently with reduced emissions and support to fulfill the requirement of the UN Environment SDG 7 goal.

Methodology

Sample selection and preparation

Lignite coal gained from Thar Block-II and rice husk samples collected from locally Sindh province Pakistan were tested. Samples were pulverized to 60 meshes particle size by a local ball mill. Sample assortment, preparation, and investigative procedures were accompanied according to the ASTM techniques. The samples were determined for air-dry loss in an air-drying oven (ASTM D-3302) as well as crushed and pulverized to 60 meshes (ASTM D-2013).

Coal and rice husk biomass analysis

The research data on As-determined (Ad) basis was changed into As-received (AR) basis (ASTM D-3180). Proximate analyses of coal, rice husk, and their blends were conceded out rendering to the ASTM standard procedure (D-3172–5). In proximate analysis, muffle furnace Volcan USA (Model A-550) was used for volatile matter, moisture, ash contents, and fixed carbon. The sample moisture was measured in a dehydrating oven at a temperature 105–110 °C by the sample weight loss. For volatile matters, cover crucible comprising the residue after moisture test then heat at a constant temperature 950 ± 20 °C for accurately 10 min in a muffle furnace. Ash contents were deliberate at 750 °C by the remains left after heating the sample until the persistent weight was attained. The fixed carbon value is intended by deducting the sum of the percentages of moisture, volatile matter, and ash from 100.

Ultimate analysis of coal, rice husk, and their mixtures were conceded out by ASTM procedure (D-3176, D-5373). The ultimate analysis comprises hydrogen (H), carbon (C), nitrogen (N), sulfur (S), and oxygen (O_2) substances. For the examination of C, H, N, and S substances, the Elementar CHNS analyzer is used. The machine is assembled upon gas chromatographic column and thermal conductivity detector. The analyzer is completely computer companionable and fixed with an auto-sampler. Oxygen is measured by subtracting from 100 the sum of the other elements of the ultimate analysis. Heating/calorific values of coal, rice husk, and their mixtures have been determined rendering to ASTM standard procedure (D-2015) bomb calorimeters.

Coal and rice husk biomass blending

Coal-rice husk blend samples of several proportions were prepared. Rice husk was assorted with coal at fraction of 10%, 20%, and 30% correspondingly. In this method, three altered samples of mixtures were made, viz., CR_h-1 comprises 90% coal and 10% rice husk, CR_h-2 comprises 80% coal and 20% rice husk, and CR_h-3 comprises 70% coal and 30% rice husk. Coal samples were assorted in diverse proportions shown in Tables 1 and 2.

Combustion and emission analysis

Harmful emissions such as CO, CO_2, NOx, and SO_2 were examined by co-firing in muffle furnace Volcan USA (Model A-550) and Testo flue gas analyzer (Model-350) for emissions monitoring. At furnace temperature around 850 °C coal and rice husk blend, samples were heated. By co-firing, emission was discharged from the stack of the muffle furnace. The probe of the gas analyzer was introduced into the furnace exit. Emissions were analyzed using a flue gas analyzer with the capability to analyze CO, CO_2, NOx, and SO_2 emissions as per USEPA Standard methods (CTM-034 and 6C).

Table 2 Ultimate analysis of Thar lignite coal, rice husk, and their blends

Samples	Ultimate analysis (%)				
	Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen
Thar lignite coal	36.73	7.53	0.58	1.51	35.38
Rice husk biomass	34.23	5.78	1.31	0.18	37.17
CRh-1 (90 TL/10 RH)	36.23	6.36	0.63	1.39	35.68
CRh-2 (80 TL/20 RH)	35.73	6.93	0.69	1.17	35.90
CRh-3 (70 TL/30 RH)	35.23	7.50	0.75	0.99	36.11

Results and discussion

Rice is cultured generally in Punjab and the Sindh provinces of Pakistan. The production of rice husk in Sindh is around 23110 tones/year (Iqbal et al. 2018). Lignite coal was obtained from Thar Block-II (Fig. 1).

Coal and rice husk proximate analysis

As displayed in Table 1 and Fig. 2, the coal comprises higher moisture content (47.30%), fixed carbon (18.12%), and calorific value (3687.60 kcal/Kg) while lower the volatile matter (29.13%) and ash (5.45%). However, rice husk is higher in the volatile matter (61.98%), lower in fixed carbon (10.57%), moisture (12.76%), and higher ash (14.69%).

Table 1 Proximate analysis of Thar lignite coal, rice husk, and their blends

Samples	Proximate analysis (%)				Calorific value
	Moisture	Volatile matter	Ash contents	Fixed carbon	(kcal/kg)
Thar lignite coal	47.30	29.13	5.45	18.12	3687.60
Rice husk biomass	12.76	61.98	14.69	10.57	3207.10
CRh-1 (90 TL/10 RH)	43.57	33.23	7.0	16.20	3424.66
CRh-2 (80 TL/20 RH)	38.89	38.98	7.55	14.58	3476.95
CRh-3 (70 TL/30 RH)	34.11	45.02	8.09	12.78	3555.37

Coal and rice husk ultimate analysis

Ultimate analysis of the coal sample gave higher carbon content of 36.73%, hydrogen at 7.53%, and sulfur at 1.51% and lower nitrogen at 0.58%, as shown in Table 2 and Fig. 3. The rice husk sample offered a lower 34.23% of carbon, 5.78% of hydrogen, 0.18% of sulfur, and higher 1.31% nitrogen. The basic configuration of the rice husk fluctuates depending on its source and environmental circumstances.

Coal-rice husk blended samples proximate and ultimate analysis

The diverse samples of coal-rice husk blend CR_h-1, CR_h-2, and CR_h-3 were evaluated. CR_h-1 gave higher moisture content of 43.57%, fixed carbon of 16.20%, and lower ash of 7.0%. CR_h-3 gave a higher volatile matter content of 45.02% and lower moisture of 34.11% as shown in Table 1 and Fig. 2. Coal-rice husk blends ultimate analysis was conceded

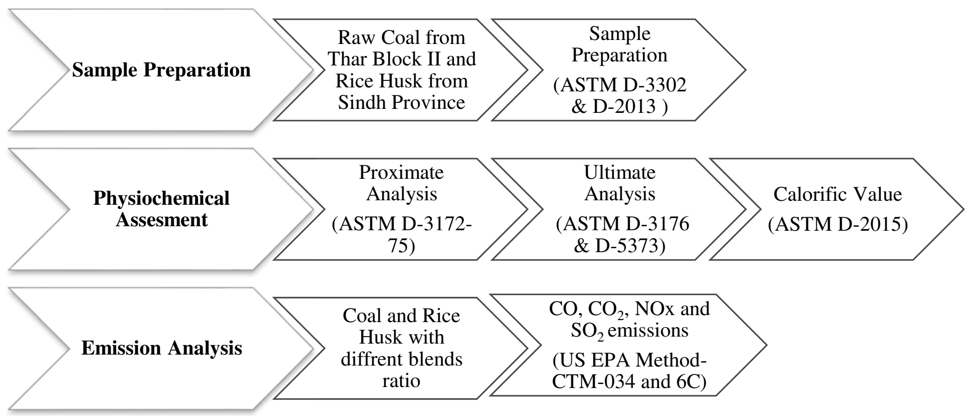

Fig. 1 Flow chart showing sequence of coal and rice husk sample preparation and analysis

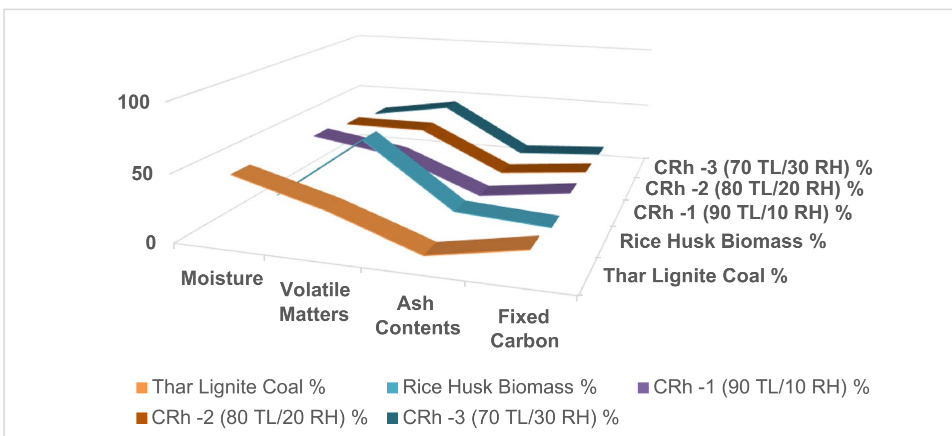

Fig. 2 Proximate analysis of Thar lignite coal, rice husk, and their blends

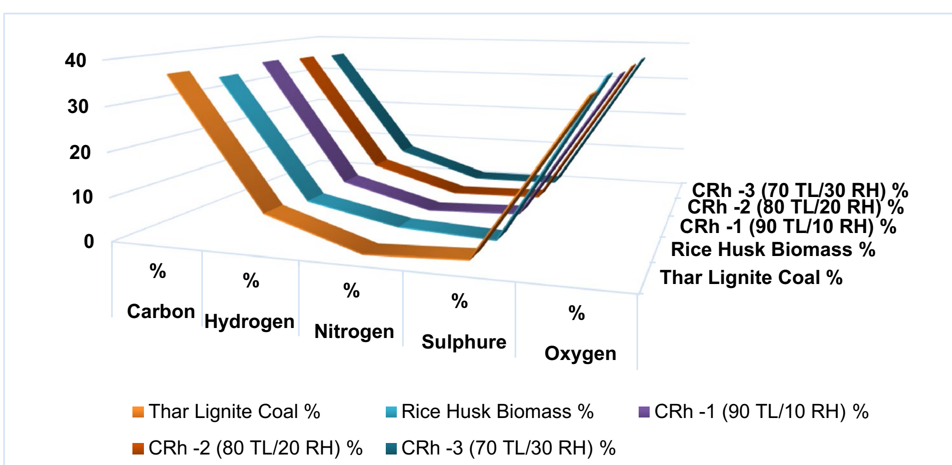

Fig. 3 Ultimate analysis of Thar lignite coal, rice husk, and their blends

out, and CR_h-1 gave a higher amount of carbon content 36.23% and a lower amount of hydrogen 6.36%, nitrogen 0.63%, and sulfur 1.39%. It was observed that the overall sulfur percentage declined in sample CR_h-3, 0.99%, whereas hydrogen and nitrogen content is increased as revealed in Table 1 and Fig. 3.

Emission analysis coal-rice husk blends

An emission study is a portion of a burning system conceded out for enhancing the fuel budget, decrease of adverse emission discharges and protecting the fuel-burning device. Burning inspection initiates with the quantity of exhaust gas concentrations. Flue gas discharges were conceded out at the laboratory in a muffle furnace for combustion and emissions, flue gas analyzer was used for O_2, CO_2, CO, SO_2, and NOx as shown in Table 3 and Fig. 4. Different gases are discharged in flue gases, which show the utilization of O_2 in the oxidation reactions throughout the burning, which caused the carbon bonds breakdown and CO_2 production. The sulfur contented in coal and biomass act with O_2 to produce SO_2, whereas the nitrogen contented generally acts with O_2 to produce NOx (NO, NO_2) (Kanwal et al. 2021).

Table 3 Emission analysis of coal-rice husk different blends

Component	O_2 %	NOx ppm	SO_2 ppm	CO ppm	CO_2 ppm
CR_h-1 (90 TL/10 RH)	5.49	89	828	1031	4.46
CR_h-2 (80 TL/20 RH)	6.41	69	649	922	5.45
CRh-3 (70 TL/30 RH)	9.07	34	169	789	7.27

Oxides of carbon emissions

The coal and rice husk emissions analysis from the co-combustion is shown in Table 3 and Fig. 4. The co-burning of 90:10% (CR_h-1) coal and rice husk biomass showed a CO and CO_2 value of 1031 ppm and 6.49% respectively, whereas 70:30% (CR_h-3) coal and rice husk ratio made CO 789 ppm and CO_2 9.96%. Once the CO value was high, the CO_2 value was low. The reduction in CO is because of the transformation of CO to CO_2 with a temperature rise. Also, biomass combination caused less carbon type resulting in the CO discharges being decreased with a rise in blending fraction and increase in furnace temperature. Furthermore, the occurrence of rice husk oxygenates would have helped the conversion of CO_2 from CO; hence, CO discharges might be relatively lesser (Akhtar et al. 2018

Oxides of nitrogen emissions

The maximum NOx level was reported in CR_h-1 (89 ppm) and the minimum in CR_h-3 (34 ppm) as shown in Table 3 and Fig. 4. Nitrogen oxides (NOx) are the most significant emissions resultant from the burning of fuels. Characteristically main NOx discharges from co-firing are NO and NO_2. NOx discharges rely on the occurrence of nitrogen in the coal, air (O_2), and co-firing course circumstances (Kumar 2017). Furthermore, a 90:10% (CR_h-1) blend of coal and rice husk formed more NOx discharges as compared to 70:30% (CR_h-3). Hence, the blending of coal-rice husk would decrease NOx production from vent gas (Munir 2011).

Oxides of sulfur emissions

SO_2 discharge relies upon the occurrence of sulfur content (Mittal et al. 2012). It is evaluated that all the existing coal sulfur is transformed into SO_2 discharges in the course of

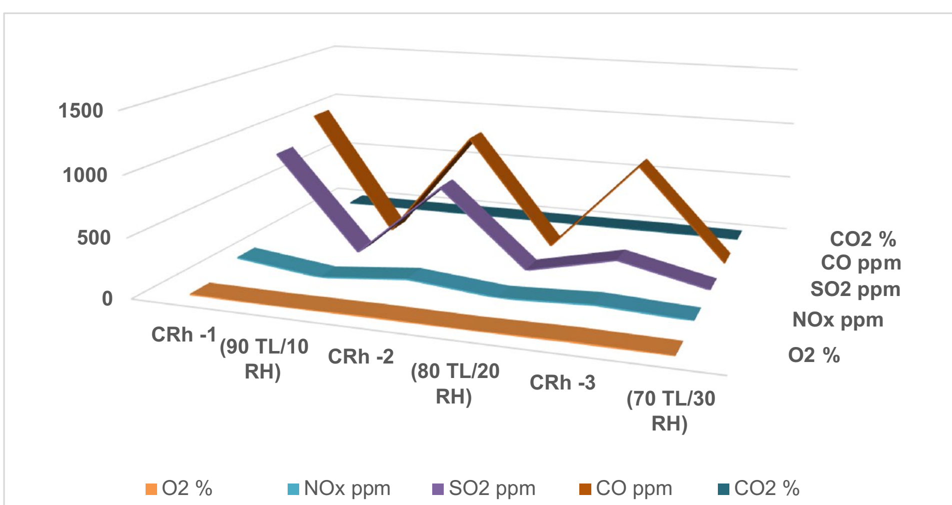

Fig. 4 Coal-rice husk blends emission

co-firing. Coal-rice husk blends discharged SO_2 in CR_h-1 (828 ppm), CR_h-2 (649 ppm), and CR_h-3 (169 ppm) respectively as shown in Table 3 and Fig. 4. Overall, the SO_2 discharges were considerably reduced by increasing the rice husk biomass ratio. This reduction in SO_2 discharges according to the blending proportion might be accredited to the dilution influence of rice husk in coal. Additionally, the rice husk ash comprises a substantial amount of CaO that might be stimulating to fix SO_2 as $CaSO_4$ (Akhtar et al. 2018).

Conclusion

Thar Coal Block II comprises higher content of moisture and sulfur, while lower in the volatile matter and ash. However, rice husk is higher in volatile matter, and lower in moisture and sulfur with higher ash. By adding biomass rice husk in Thar coal, its basic configuration changed and provided lesser sulfur and other content as related to the coal. This study explores the coal-rice husk blending effects on coal configuration and emission gases. It was observed that the blending fraction facilitated decreased discharges of SO_2 and NOx. A decline in SO_2 and NOx discharges was found by increasing the blending ratio. NOx and SOx emissions reduced from 89 ppm (CR_h-1) to 34 ppm (CR_h-3) and 828 ppm (CR_h-1) to 169 ppm (CR_h-3) respectively by increasing the blending percentage from 10 to 30%. Samples of coal and rice husk blend 70:30% (CR_h-3) were found to be feasible for the power production point of opinion for the reason of low emissions gases, high calorific value, and volatile substances and low moisture and ash contents as related to other blended samples. In addition to that, low sulfur was observed in this blend, which marks it a possible contestant for energy production in environmentally friendly conditions. Coal-rice husk blends provide effective burning and decrease NOx and SOx discharge to resolve the environmental problem of coal-related emissions. Hence, the usage of rice husk might be a beneficial selection to decrease discharges of SO_2 and NOx throughout burning and support fulfilling the requirement of the UN Environment SDG 7 clean energy goal. The utmost advantageous and effective tool for co-combustion energy creation is circulating fluidized bed combustor (CFBC) as they allow cleaner and further effective coal utilization to decrease emissions.

Declarations

Conflict of interest The authors declare no competing interests.

References

Abaide ER, Tres MV, Zabot GL, Mazutti MA (2019) Reasons for processing of rice coproducts: reality and expectations. Biomass Bioenergy 120:240–256. https://doi.org/10.1016/j.biombioe.2018.11.032

Abdeshahian P, Lim JS, Ho WS, Hashim H, Lee CT (2016) Potential of biogas production from farm animal waste in Malaysia. Renew Sust Energy Rev 60:714–723. https://doi.org/10.1016/j.rser.2016.01.117

Ahmad A, Hakimi MH, Chaudhry MN (2015) Geochemical and organic petrographic characteristics of low-rank coals from Thar coalfield in the Sindh Province, Pakistan. Arab J Geosci 8:5023–5038. https://doi.org/10.1007/s12517-014-1524-6

Akhtar J, Yaseen A, Munir S (2018) Effect of rice husk co-combustion with coal on gaseous emissions and combustion efficiency. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 40(8):1010–1018. https://doi.org/10.1080/15567036.2018.1468513

Akram R et al (2018) Paddy land pollutants and their role in climate change. In: Hashmi M, Varma A (eds) Environmental pollution of paddy soils. Soil biology, vol 53. Springer, Cham. https://doi.org/10.1007/978-3-319-93671-0_7

Arenillas A, Rubiera F, Arias B, Pis JJ, Faúndez JM, Gordon AL, García XA (2004) A TG/DTA study on the effect of coal blending on ignition behavior. J Therm Anal Calorim 76(2):603–614. https://doi.org/10.1023/B:JTAN.0000028039.72613.73

Bariani M, Boix E, Cassella F, Cabrera MN (2020) Furfural production from rice husks within a biorefinery framework. Biomass Conv Bioref:1–14. https://doi.org/10.1007/s13399-020-00810-1.

Boerrigter H, Rauch R (2005) Review of application of gassses from biomass gasification. Chap. 10 in Handbook Biomass gasification, by H.A.M.Knoef, 211–230. Viena: Biomass Technology Group (BTG), Viena University of Technology, Institute of Chemical Engineering

Cardozo E, Erlich C, Alejo L, Fransson TH (2016) Comparison of the thermal power availability of different agricultural residues using a residential boiler. Biomass Conv Bioref 6(4):435–447. https://doi.org/10.1007/s13399-016-0200-3

Chieng S, Kuan SH (2020) Harnessing bioenergy and high value-added products from rice residues: a review. Biomass Conv Bioref:1–25. https://doi.org/10.1007/s13399-020-00891-y

EIU Report (2017) http://www.eiu.com/industry/article/825415066/betting-on-coal-to-solve-the-electricity-shortage/2017-05-11. The Economist Intelligence Unit. Accessed 11th May 2017

Gautam N, Ram KV, Chaurasia A (2020) Study on chemical kinetics and characterization of nano-silica from rice husk and rice straw in the fixed-bed pyrolysis process. Biomass Conv Bioref:1–14. https://doi.org/10.1007/s13399-020-00838-3

Hussain S, Shahzad K, Akthar KS, Akhthar NA, Chughtai A (2015) Investigations of thermal conversion and kinetics of low-grade coal and bagasse using thermogravimetric technique. J Faculty Eng Technol (JFET) 21(2):105–117

Iqbal T, Dong C, Lu Q, Ali ZK, Hussain Z, Abbas A (2018) Sketching Pakistan's energy dynamics: prospects of biomass energy. J Renew Sustain Energy 10(2):023101. https://doi.org/10.1063/1.5010393

Irfan M, Zhao ZY, Panjwani M K, Mangi FH, Li H, Jan A, Ahmad M, Rehman A (2020) Assessing the energy dynamics of Pakistan: prospects of biomass energy. Energy Reports. 6: 80–93, ISSN 2352–4847, https://doi.org/10.1016/j.egyr.2019.11.161

Kanwal F, Ahmed A, Jamil F, Rafiq S, Ayub HMU, Ghauri M, Khurram M, Munir S, Inayat A, Abu Bakar MS (2021) Co-combustion of blends of coal and underutilized biomass residues for environmental friendly electrical energy production. Sustainability 13:4881. https://doi.org/10.3390/su13094881

Kumar D, Soomro SA, Mahar HU, Aziz S, Unar IN, Memon AR, Malik AA, Hussain S (2017) Co-firing of brown coal &bagasse for sulfur reduction. Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan 22(II): 113–118

Malkani MS (2012) A review of coal and water resources of Pakistan. J Sci Technol Dev 31(3):202–218

Mittal ML, Sharma C, Singh R (2012) Estimates of emissions from coal fired thermal power plants in India. 20th Emission Inventory Conference, August 13–16. 2012. Tampa, Florida, 1–22

Muneer T, Asif M (2007) Prospects for secure and sustainable electricity supply for Pakistan. Renew Sustain Energy Rev 11(4):654–671

Munir S (2011) Co-combustion of coal with biomass: energy for a clean environment. VDM Verlag Dr. Müller, ISBN-10: 3639327985, ISBN-13: 978-3639327984

Naseem S, Abid MI, Kamran M, Fazal MR, Abbas G, Abid MR, Zamir Z (2020) Rural areas interoperability framework: intelligent assessment of renewable energy security issues in Pakistan. International Journal of Smart Grid, Vol.4 (2). DOI (PDF): https://doi.org/10.20508/ijsmartgrid.v4i2.93.g89

Nazar M, Yasar A, Raza SA, Ahmad A, Rasheed R, Shahbaz M, Tabinda A B (2021) Techno-economic and environmental assessment of rice husk in comparison to coal and furnace oil as boiler fuel. Biomass Conv Bioref:1–9. https://doi.org/10.1007/s13399-020-01238-3

Quispe I, Navia R, Kahhat R (2017) Energy potential from rice husk through direct combustion and fast pyrolysis: a review. Waste Manag 59:200–210. https://doi.org/10.1016/j.wasman.2016.10.001

Raheem A, Abbasi SA, Memon A, Samo SR, Taufiq YH, Danquah MK, Harun R (2016) Renewable energy deployment to combat energy crisis in Pakistan. Energy Sustain Soc 6(16). https://doi.org/10.1186/s13705-016-0082-z

Saini JK, Saini R, Tewari L (2015) Lignocellulosic agriculture wastes as biomass feedstocks for second-generation bioethanol production: concepts and recent developments. Biotech 5(4):337–353

Shahbaz M, Al-Ansari T, Aslam M, Khan Z, Inayat A, Athar M, Naqvi SR, Ahmed MA, McKay G (2020) A state of the art review on biomass processing and conversion technologies to produce hydrogen and its recovery via membrane separation. Int J Hydrog Energy 45(30):15166–15195. https://doi.org/10.1016/j.ijhydene.2020.04.009

Sharma MP (2016) Selection of potential oils for biodiesel production. Renew Sust Energ Rev 56:1129–1138. https://doi.org/10.1016/j.rser.2015.12.032

Siddiqi MH, Hussain MA, Iqbal T, Tabish AN, Mahmood W, Qureshi T (2018) Combustion and pyrolysis study of Pakistani coal, rice husk, and their blends via TGA analysis. ICECE:43–48. https://doi.org/10.1109/ECE.2018.8554987

Suksankraisorn K, Patumsawad S, Vallikul P, Fungtammasan B, Accary A (2004) Co-combustion of municipal solid waste and Thai lignite in a fluidized bed. Energy Convers Manage 45(6):947–962

Tauqeer HM, Turan V, Farhad M, Iqbal M (2022) Sustainable agriculture and plant production by virtue of biochar in the era of climate change. In: Hasanuzzaman M, Ahammed GJ, Nahar K (eds) Managing plant production under changing environment. Springer, Singapore. https://doi.org/10.1007/978-981-16-5059-8_2

Xu Q (2013) Investigation of co-gasification characteristics of biomass and coal in fluidized bed gasifier. Dissertation, Chemical and Process Engineering, Canterbury: University of Canterbury, 2013: 180-190

Zhong Z, Jin B, Huang Y, Zhou H, Lan J (2006) Experimental research on emission and removal of dioxins in flue gas from co-combustion of MSW and coal incinerator. Waste Manage 26(6):580–586. https://doi.org/10.1016/j.wasman.2005.06.002