Burning of Crop Residue and its Potential for Electricity Generation

Tanvir Ahmed* and Bashir Ahmad**

*Associate Professor, Department of Economics, Forman Christian College (A Chartered University), Lahore. Email: tanvirahe@yahoo.com

**Professor Emeritus, Institute of Agricultural and Resource Economics, University of Agriculture, Faisalabad. Email: bashiruaf@gmail.com

Abstract

This paper identified the factors influencing the rice crop residue burning decision of the farmers and the potential of the burnt residue to generate electricity. For this study, data were collected from 400 farmers in the rice-wheat cropping system. Effects of different variables on the adoption of burning of rice residue are investigated by using logit model. The overall quantity of rice straw burnt is estimated to be 1704.91 thousand tonnes in the rice–wheat cropping system with a potential to generate electric power of 162.51 MW. This power generation from crop residues would be a source of income for the farmers from the rice residue along with generation of additional employment opportunities and economic activities on sustainable basis

1. Introduction

Most of villages in Punjab have electricity supply but supply of electricity to these rural areas is inadequate. These villages have to face most of time electricity shut down because of severe electricity shortage in Pakistan due to excess demand for electricity. Currently, major portion of electricity is generated by using fossil fuel. Generation of electricity through burning of fossil fuel generates greenhouse gases. Moreover, high oil prices have adverse impacts on the economy of Pakistan. Thus, it is important to explore new means of electricity generation due to its shortage.

Bioenergy shares about 10 percent of total energy consumption and it is expected that this source will play greater role in near future (Jiang et. al., 2012). Research work indicates that open field burning of crop residue is a common practice in many countries (Gadde et. al., 2009). It has been estimated that annually on average 730 Tg of biomass are burnt in Asia and out of which 250 Tg come from agricultural burning. Open burning of biomass is emitting 0.37 Tg of SO_2, 2.8 Tg of NOx, 1100 Tg of CO_2, 67 Tg of CO and 3.1 Tg of methane. However, emissions of crop residues burning is contributing about 0.10 Tg of SO_2, 0.96 Tg of NOx, 379 Tg of CO_2, 23 Tg of CO and 0.68 Tg of CH_4 (Streets et. al., 2003). A growing major concern regarding residue burning emerges from its effects on air pollution and climate change. Incomplete combustion of biomass such as agricultural residues generates black carbon (Kante, 2009; Bond et. al., 2013) which is the second largest contributor to global warming after carbon dioxide (UNEP, 2009; Chung et. al., 2005; 2007; Ramanathan and Carmichael, 2008). Black carbon absorbs radiation and warms the atmosphere at regional and global scales. Increased concentration of black carbon and other pollutants, observed in the high Himalayas, is expected to enhance glacier melting. Black carbon emissions and other types of aerosols have also given rise to atmospheric brown clouds (ABCs) in Asia (Nakajima, 2009). The aerosols in ABCs decrease the amount of sunlight reaching the earth's surface by 10 percent to 15 percent and enhance atmospheric solar heating by as much as 50 percent (UNEP.RRC.AP., 2012). One estimate attributes 30 percent to 50 percent of the human contributions to global warming to black carbon, methane and ozone (Ramanathan et. al., 2009). In general, ABCs and their interactions with greenhouse gases significantly affect climate, hydrological cycle, glacier melting, agricultural and human health (UNEP.RRC.AP., 2012). Thus, all it indicates that open field burning of crop residue is the most undesirable treatment of crop residue from the perspective of environmentalists. This treatment of crop residue also worsens the problem of global warming.

Rice-wheat cropping system is dominant in the Indo-Gangetic Plain (IGP) which comprises of parts of Pakistan, India, Bangladesh, and Nepal. IGP is producing enormous quantity of rice straw and it is usually not used as feed for animals (Badarinath et al., 2006). Consequently, rice residues are generally burnt and it is often questioned, why farmers burn it? Research work done shows that burning of rice residues increases the short-term availability of some nutrients i.e. P and K (Erenstein, 2002) but also results in the loss of plant nutrients (Biederbeck et. al., 1980; Heard et. al., 2006; IRRI-CIMMYT Alliance; Gupta et. al., 2004) besides health and environmental problems (the Lung Association, 2009; Nori, 2005; Graham et. al., 1986; Prasad and Power, 1991). Burning of crop residues also reduces microbial population (Raison, 1979) and organic carbon (Rasmussen et. al., 1982; Heard et. al., 2006). However, incorporation of crop residue increases organic carbon and nutrient contents of soils (Sharma et. al., 1985; Sidhu and Beri, 1989; Ganwar et. al., 2006; Hartley and Kessel, 2005; Kessel and Horwath; Prasad et. al., 1999) and crop yield (Hooker et. al., 1982; Bhatnagar et. al., 1983; Garg, 2008; Surekha et. al., 2003; Prasad et. al., 1999; Tripathi et. al., 2007).

There is an increasing interest in converting crop residues to energy products due to new emerging technologies and rising energy prices (Idania et. al., 2010; Scarlat et. al., 2010). There are number of studies that indicate the existence of potential of electricity generation through the usage of crop residue as a fuel in power generation plants (Freedman, 1983; Ergudenler and Isigigur, 1994; Shyam, 2002; Jingura and Matengaifa, 2008; Karaj et. al., 2010; Hiloidhari and Baruah, 2011; Nguyen et. al., 2013). Liquid or gaseous biofuel can be produced from crop residues like cereals and corn, by using thermo–chemical or biological techniques (Elmore et. al., 2008). Hiloidhari and Baruah (2011) found 16 different types of crop residue in Sonitpur district of Assam, India. They found rice crop as dominant residue and about 0.17 million tonnes of residue biomass has a potential of about 17MW power. According to them, decentralized crop residue based power generation can solve the problem of acute shortage of grid connected power supply. Similarly, Nguyen et. al. (2013) estimated the electricity generation from wheat straw instead of coal and natural gas. Their study also indicates that usage of straw will reduce global warming and use of non-renewable energy. Hence, there is an increasing recognition that interrelations between agriculture, biomass productions, bio-energy and climates should be better understood in order to estimate the realistic estimates of bioenergy potential (Haberal et. al., 2011). According to Freedman (1983), a huge potential of biomass energy is available in rural areas in the form of rice crop residue. Potential amount of energy that can be obtained from this residue is 3.70×10^{10} J/ha/year under traditional methods, $7.93 \text{ X } 10^{10}$ J under labor intensive and $8.36 \text{ X } 10^{10}$ J under capital intensive methods. The accurate estimates of the amounts of produced crop residues, their disposal pattern (quantity used as feed for animals, quantity used as fuel for cooking, quantity incorporated into soil, quantity burnt to clear the field in order to improve the performance of farm machinery for bed preparation for the next crop, etc.) and the potential amount of crop residue that can be saved from burning and used for bioenergy generation on sustainable basis is very important. According to Jingura and Matengaifa (2008), biomass can provide 47 percent of the energy consumption in Zimbabwe and crop residue is major component of this biomass. According to them, estimated annual amount of crop residue in Zimbabwe is 7.805 Mt and it has an energy potential of 81.5 PJ per year. Thus crop residue has potential of usage of energy generation besides feeding of animals and improvement of soil fertility. Moreover, environmental advantage connected with this change from burning of residue to electricity generation can be revealed from the fact that this change has no competition with food or cash crops and no land use change is required (Barz and Delivand, 2011). Shyam (2002) identified crop residue as a sustainable source of energy supply and suggested establishment of decentralized electricity supply system based on crop residue in rural areas. Likewise, Karaj et. al. (2010) analyzed the existence of potential of electricity generation in Albania through biomass (bioenergy crops, agricultural and forestry residues and wastes). They considered generation of steam and biogas from the biomass to run steam generators and turbines for the generation of electricity. Energy content in biomass was estimated theoretically by estimating biomass using statistical reports, literature review and personal investigations. For Albania, it is found that 4.8 million tons of dry biomass was produced in year 2005 with energy content 11.6 million MWh/a. This energy content has technically potential of 3 million MWh/a of electrical energy production. This amount of electrical energy is equal to 45.8 percent of total electrical consumption of Albania. Study of Ergudenler and Isigigur (1994) identified agricultural residue as a potential fuel for sustainable electricity generation in Turkey. According to them, usage of agricultural residue in power plants has less environmental impacts and results in the reduction of net emissions of CO_2, SO_2 and NO_x as compared to thermal power plants in which lignite is major source of fuel. Similarly, rice crop residue has huge potential of electricity generation in rural areas of Pakistan. As in Pakistan, major portion of rice crop residue is burnt in fields. Experimental data indicates that this open field burning of residue has no positive impact on the soil fertility. Moreover, this act has adverse negative impacts on the environment because of greenhouse gas emissions. So by using this residue for electricity generation, one can avoid the problem of greenhouse gas emissions and intensity of problem of electricity shortage.

This study is carried out to answer two questions

1. What are the factors which influence the decision of burning the rice residue and
2. What is the quantity of electricity that can be produced by using the rice straw that is currently being burnt.

2. Methodology

The first part of the methodology presents a model to answer the question why the farmers burn the rice residue. The second part is concerned with the methodology used in estimating the potential of electricity that can be generated from the residue that is being burnt by farmers. Finally, procedure used for data collection is presented.

2.1. Logit model of residue burning decision

Adoption of burning or non-burning residue management practice essentially involves a choice by the farmer. Binary choice models are more appropriate when choice is to made between the two alternatives (Judge et. al., 1980; Pindyck and Rubinfeld, 1981). The linear probability model suffers from a number of deficiencies i.e. variance of the disturbance is heteroscedastic, the distribution of this term is not normal and it does not constrain the predicted values to lie between 0 and 1 (Amemiya, 1981; Capps Jr. and Kramar, 1985). Problems of the linear probability model can be overcome through the monotonic transformation (Probit or logit specification) and it guarantees that predictions lie in the unit interval (Capps Jr. and Kramar, 1985). The choice of model i.e. probit or logit is mainly a question of convenience (Hanushek and Jackson, 1977). In this paper, logit model is used. A farmer will make his choice based on the rule of utility maximization. According to this rule, farmer i selects the alternative from the choice set that maximizes his utility U_i. Since the researcher does not have complete information about all the factors that are considered important in the decision making process by farmers while making a choice, so the utility function U_{ij} is broken down into two components (Guadagni and Little, 1983), i.e

$U_{ij} = V_{ij} + \varepsilon_{ij}$ Where U_{ij} is the overall utility of i-th farmer for j-th choice,

V_{ij} is a systematic utility component of i-th farmer for j-th choice,

ε_{ij} is a stochastic component of i-th farmer for j-th choice.

The decision maker chooses the alternative from which he gets the maximum utility. In the binomial or two alternatives case, farmer chooses alternative 1 if and only if.

$$U_{i1} \geq U_{i2}$$

Or

$$U_{i1} + \varepsilon_{i1} \geq U_{i2} + \varepsilon_{i2}$$

In probabilistic terms, the probability that alternative 1 is selected is given by

$$\Pr(1) = \Pr(U_{i1} \geq U_{i2}) = \Pr(V_{i1} + \varepsilon_{i1} \geq V_{i2} + \varepsilon_{i2}) = \Pr(\varepsilon_{i2} - \varepsilon_{i1} \leq V_{i1} - V_{i2})$$

It states that the probability of choosing alternative 1 is equal to the probability that the difference in stochastic utility is less then or equal to the difference in systematic utility. Assuming that $\varepsilon_{i2} - \varepsilon_{i1}$ has a logistic distribution, the probability (P_i) that farmer i burns residue is a function of an index variable (Z_i) summarizing a set of farmer attributes, can be written as:

$$P_i = F(z_i) = \frac{e^{Z_i}}{1+e^{Z_i}} \text{ Where } Z_i = X_i^{/}\beta$$

Where β is a vector of coefficients; X_i is a vector of the i-th farmer attributes and e is the base of natural logarithm. Z_i is a dichotomous variable, it takes the value of one if a farmer has adopted the practice of residual burning and takes the value zero otherwise.

The change in P_i with respect to change in X_i is given by

$$\frac{\partial P_i}{\partial X_i} = (\frac{\partial F}{\partial z_i})(\frac{\partial z_i}{\partial x_i}) = f(z_i)\beta = \frac{e^{x_i^{/}\beta}}{1+e^{x_i^{/}\beta}}\beta_k$$

Where β_k is the k-th element of the parameter vector β.

As P_i is equal to one if a choice is made and zero otherwise so the correct estimation procedure is maximum likelihood. The probability that the farmer burn the rice residue depends upon various attributes like farm size, number of farm fragments, livestock strength, age, education, farming experience and caste of farmer, ownership of farm, soil type, use of rice residue as feed, fuel, cost of collection and transportation of rice residue etc. Therefore, the following model is used to analyze the decision of rice residue burning:

$$
\begin{aligned}
BURN_i = {} & \beta_0 + \beta_1 AGE_i + \beta_2 EXP_i + \beta_3 PRIM_i + \beta_4 UPMAT_i + \beta_5 AMATR_i + \beta_6 JAT_i \\
& + \beta_7 ARIAN_i + \beta_8 RAJPUT_i + \beta_9 SIZE_i + \beta_{10} ONWER_i + \beta_{11} OWNCT_i + \beta_{12} FRAGM_i \\
& + \beta_{13} SILTL_i + \beta_{14} CLAY_i + \beta_{15} ANIMAL_i + \beta_{16} TCBURN_i + \beta_{17} WHTSOWN_i \\
& + \beta_{18} MACH + \beta_{19} FEED_i + \beta_{20} FUEL_i + \beta_{21} PBASM_i + \beta_{22} INSECT_i \\
& + \beta_{23} REDTURN_i + \beta_{24} CONMACH_i + \beta_{25} COLTRAL_i + \beta_{26} GUJRAN_i + \varepsilon_i
\end{aligned}
$$

Where, the variables are defined in table 1.

Table 1: Variable Definitions

Variable Name	**Description**
BURN	1 if farmer adopted the practice of rice crop residue burning; 0 otherwise
AGE	Age of farmer in years
EXP	Farming experience of farmer in years
PRIM	1 if farming is the primary occupation; 0 otherwise
UPMAT	1 if educational level of farmer is upto matric; 0 otherwise
AMATR	1 if education level of farmer is above matric; 0 otherwise
JAT	1 if caste of farmer is Jat; 0 otherwise
ARIAN	1 if caste of farmer is Arian; 0 otherwise
RAJPUT	1 is caste of farmer is Rajput; 0 otherwise
SIZE	Operational size of farm in acres
OWNER	1 if farmer is owner operator; 0 otherwise
OWNCT	1 if farmer is owner-cum-tenant; 0 otherwise
FRAGM	Number of places where the farm land is situated
SILTL	1 if the dominant soil type is silt loam; 0 otherwise
CLAY	1 if the dominant soil type is clayey; 0 otherwise
ANIMAL	Number of animal units on the farm
TCBURN	Total cost associated with the handling the residue and preparation of wheat field after rice
WHTSOWN	1 if wheat is sown before the end of November; 0 otherwise
MACH	1 if farm machinery is available for incorporation; 0 otherwise
FEED	1 if rice residue is used as feed for animals; 0 otherwise
FUEL	1 if rice residue is used as fuel; 0 otherwise
PBASM	Proportion of rice acreage allocated to super basmati and 385 basmati to total rice acreage
CINSECT	1 if the intention of respondent is to control insects, weeds and diseases; 0 otherwise
REDTURN	1 if the intention of respondent is to reduce turnaround time between harvesting of rice and sowing of wheat; 0 otherwise
CONMACH	1 if burning of residue results in convenience in use of farm machinery; 0 otherwise
COLTRAN	Total cost associated with collection and transportation of rice residue
GUJRAN	1 if farm is located in Gujranwala district; 0 otherwise

2.2. Methodology for determining the potential of electricity generation from rice residue

Following steps are involved for calculating the generation of electricity from rice residue.

2.2.1. Determining the total yield of rice crop and residue

Availability of accurate data about the crop residue is very essential for determining the potential of bioenergy in any country. Previous studies estimated the straw produced from the main product like grain and used a specific ratio of main product to straw to estimate the straw produced. Such a ratio of main product to straw varies from variety to variety and sometime even for a specific product because of differences in climatic and agronomic conditions under which the main product is produced. Consequently, the estimate of amount of crop straw produced either overestimated or underestimated the actual amount of straw produced. This study uses primary data collected from the farmers for the assessment of the quantity of straw produced and its disposal pattern. In this study in to order obtain the yield of rice crop and its residue, farmers were asked about the variety grown, area under each variety, yield of paddy and straw. This information was used to calculate the paddy yield and straw yield which came to 1624 kg and 1602 kg, respectively. Thus the ratio of paddy to straw was 1:0.99. This ratio was quite comparable with the ratio of 1:1 reported by Jiang et. al. (2012).

2.2.2. Rice area under various residue management practices

In the study area, farmers were following different practices to manage the rice residue. Therefore, farmers were asked about the rice area managed under various residue management practices i.e. area from which residue was removed 100 percent (REMV), area from which pural was removed and lower parts of rice plant was burnt (RPBL), area from which pural and lower parts of stem were burnt (BPLP), area from which pural was removed and lower parts of stem were incorporation (RPINC) and the area where the entire residue was incorporated (INC). The area where traditional manual method was used for harvesting the residue was removed 100 percent and was used mainly as feed for animals.

2.2.3. Estimation of quantity of rice residue burnt

In two practices (i.e. RPBL and BPLP), burning of residue is involved. Moreover, there is not complete burning of residue in these practices as the lower parts of rice plant are not dry enough to catch fire. Consequently, we asked farmers about the proportion of rice residue burnt in these practices. This proportion was used to determine the quantity of rice residue burnt from the straw yield produced for each variety grown under these two practices. A weighted average quantity of residue burnt was obtained by weighing the quantity of straw burnt with the acreage of each variety for the practice RPBL and BPLP. Finally, quantity of residue burnt per acre under various residue management practices was weighted according to the acreage under each practice to determine the quantity of residue burnt per acre of rice harvested. This quantity of residue per acre was multiplied with the rice acreage in the rice wheat cropping system of Punjab, to estimate the total quantity of residue burnt. Assuming the same quantity of residue burnt per acre for the rice-wheat cropping system area, we estimated the total quantity of burnt residue in Punjab, Pakistan.

2.2.4. Estimation of biomass power potential

Conversion of biomass to energy can be done by using various technologies i.e. thermo–chemical and bio–chemical (Jiang et. al., 2012). Thermo–chemical conversion technology is specifically suitable for loose biomass (Nussbaumer, 2003). The most common process involves the direct combustion of fuels to produce thermal energy which is used to produce stream and in further steps to generate electricity by using steam turbines, steam engines or other energy converters (Barz, 2008). Biomass power plants with different sizes of combustion can generate electricity from a few kilowatts to 100 MW with net conversion efficiency from 20 percent to 40 percent (Mckendry, 2002; Nussbaumer, 2003).

In order to estimate the power potential, following expression is used.

$$RRPP_J = \frac{K \times ACR_J \times WAQRB \times LHVR}{T}$$

Where $RRPP_J$ is the rice residue biomass power potential of the J-th area; K is the overall energy conversion efficiency assuming a value of 20 percent (Hiloidhari, 2011); ACR_J is the rice acreage in acres in the J-th area; WAQRB is the weighted average quantity of rice residue burnt per acre; $LHVR$ is the lower heating value of the rice straw. It is taken to be 15.03 (G) t^{-1} (Singh et. al., 2008); T is the annual operating duration in seconds.

2.3. Data

The data for this study were collected during the year 2010 from the two most important districts (i.e. Gujranwala and Sialkot) having share of maximum acreage in the rice-wheat system of the Punjab (Government of Punjab, 2009). Ten villages were selected randomly from the 36 villages already selected by the Federal Bureau of Statistics from each of the districts for the estimation of acreage and yield of various crops. These villages were considered as primary sampling unit (PSU). Farmers within the PSUs were taken as secondary sampling unit. A list of farmers was prepared in each village and then

20 farmers were randomly selected from different sizes in proportion to their number. Total sample comprised of 400 respondents. For the collection of data, a comprehensive questionnaire was constructed which was modified after pre-testing. The data were collected by using personal interview method.

3. Results

3.1. Influence of different factors on the decision of burning of residue

Descriptive statistics of the variables used in the model are exhibited in Table 2. The means of the qualitative variables refer to the proportion of respondents taking on particular qualitative attributes. For example, approximately 77 percent of the respondents are owner operators, roughly 20 percent of the respondents are owner-cum-tenants. Similarly, approximately 57 percent of the respondents are Jat, 13 percent Rajput and 6 percent Arian. The continuous variables indicate that each farm has, on average about 11.93 acres of land and the collection and transportations cost per acre of rice residue is Rs. 485.84 (Rs.104 = 1 US$).

The maximum likelihood estimates of the logit model are presented in Table 3. Likelihood ratio indicates that the amount of variation explained is significantly different from zero. Pseudo R^2 value is 0.433. The probability of burning rice residue was significantly associated (at 20 percent level) with fifteen variables out of twenty six variables included in the model. These factors were: (a) Farming experience of the farmer (EXP), (b) Farming as the primary occupation (PRIM), (c) Rajput caste (RAJPUT), (d) Farm size (SIZE), (e) Farmer is owner operator (OWNER), (f) Farmer is owner-cum-tenants (OWNCT), (g) Soil type is silty loam (SILTL), (h) Soil type is clay loam, (i) livestock strength on the farm (ANIMAL), (j) Farm machinery availability for incorporation (MACH), (k) Use of residue as feed for animals (FEED), (l) Use of residue as fuel (FUEL), (m) Intention of the respondent to reduce turnaround time between harvesting of rice and sowing of wheat (REDTURN), (n) Burning of residue results in convenience use of farm machinery (CONMACH) and (0) The geographic location of farm in Gujranwala(GUJRAN) district.

The farming experience (EXP) had positive influence on the probability of burning rice residue. The probability of burning increased by one percent for each one percent increase in farming experience. A possible explanation for this behaviour is that 53.75 percent and 15.15 percent farmers perceive that residue burning improve the physical properties and increase soil nutrients of soil, respectively. Moreover, the results of the study show that 70.50 percent and 64.75 percent of the farmers perceive that burning of rice residue increases the yield of wheat and rice, respectively. The increase in the yield of both wheat and rice crops are due to substantial and readily availability of nutrients through ash to plants due to incomplete burning of rice residue as the temperature desired for complete burning is not achieved during the burning of residue (Kumar and Goh, 2000). Further there is rapid conversion of nutrients from organic form to inorganic form N, P, K, Ca and Mg (Sureka et. al., 2006).

The probability of burning of rice residue was increased by 1.91 percent for each percent increase in farm size (SIZE). This results from the fact that livestock strength per unit area decreases with increase in farm size and consequently the use of rice residue as feed falls.

Total cost associated with the preparation of field for wheat crop after rice was significantly related with the increase in probability of rice residue burning. The survey results show that the total cost associated with the preparation of wheat field after rice was Rs 3536.79 where the rice straw was burnt in the field compared with Rs 4097.83 for the incorporation of rice residue practice. This shows that farmers are adopting the burning practice as the cost associated with burning practice was substantially less than non-burning practice. Under the prevailing cost conditions, farmers will not decline in rice residue burning unless they are compensated appropriately by other measures.

Tenure type i.e. owner operator (OWNER) and owner-cum-tenant (OWNCT) were significantly associated with the decrease in probability of rice residue burning by 55.87 percent and 53.49 percent, respectively. This shows that owner operators and owner-cum-tenant have long-term planning horizon and are concerned more with the sustainability of land resource.

The probability of burning of rice residue was decreased by 0.65 percent for each 1 percent increase in animal strength (ANIMAL). Because the effect of animal strength on the use of rice residue is positive, therefore, farmers have adopted less burning practice.

Availability of farm machinery for incorporation (MACH) of rice residue in the soil was significantly associated with the decrease in probability of rice residue burning by 20.89 percent. This suggests that ensuring the availability of farm machinery for incorporation can help in reducing the practice of burning.

Table 2: <u>Descriptive statistics for the variables used in Logit Analysis</u>

Variable	Mean	Std. Dev.	Minimum	Maximum
AGE	47.49	15.637	17	80
EXP	27.63	15.978	1	70
PRIM	0.923	0.268	0	1
UPMAT	0.403	0.491	0	1
AMATR	0.088	0.283	0	1
JAT	0.570	0.496	0	1
ARIAN	0.063	0.242	0	1
RAJPUT	0.128	0.334	0	1
SIZE	11.929	14.934	0.62	100
OWNER	0.765	0.425	0	1
OWNCT	0.198	0.399	0	1
FRAGM	1.508	0.779	1	4
SILTL	0.623	0.485	0	1
CLAY	0.348	0.477	0	1
ANIMAL	8.921	11.406	0	130
TCBURN	3061.639	1246.474	0	7850
WHTSOWN	0.835	0.371	0	1
MACH	0.103	0.304	0	1
FEED	0.740	0.439	0	1
FUEL	0.120	0.325	0	1
PBASM	73.551	38.001	0	100
CINSECT	0.330	0.417	0	1
REDTURN	0.095	0.294	0	1
CONMACH	0.580	0.494	0	1
COLTRAN	485.835	478.800	0	4556.794
GUJRAN	0.50	0.501	0	1

Table 3: Maximum Likelihood Estimates for Logit Model

Variable	**Estimate**	**Change in Probability**	**Z statistic**
AGE	-0.0191	-0.0048	-1.100
EXP	0.0398*	0.0099	2.290
PRIM	-0.5552	-0.1357	-0.910
UPMAT	0.2375	0.0593	0.710
AMAIR	-0.4940	-0.1219	-0.720
JAT	0.0191	0.0048	0.050
ARIAN	-0.5119	-0.1260	-0.780
RAJPUT	0.9857[a]	0.2332	1.680
SIZE	0.0766**	0.0191	4.400
OWNER	-2.8688*	-0.5587	-2.240
OWNCT	-2.7415*	-0.5349	-2.070
FRAGM	-0.0493	-0.0123	-0.220
SILTL	1.1686[b]	0.2832	1.310
CLAY	0.9606	0.2341	1.080
ANIMAL	-0.0261[b]	-0.0065	-1.540
TCBURN	0.0002[a]	0.0001	1.820
WITHSOWN	0.4141	0.1028	0.940
MACH	-0.8701[b]	-0.2089	-1.550
FEED	-2.7507**	-0.5530	-6.300
FUEL	-0.9806*	-0.2335	-2.020
PBASM	0.0026	0.0007	0.640
CINSECT	0.1035	0.0259	0.220
REDTURN	1.3046*	0.2945	2.280
CONMACH	1.7715**	0.4149	4.090
COLTRAN	-0.0001	-0.0001	-0.160
GUJRAN	0.6672*	0.3186	2.090
CONSTANT	0.7673	1.9147	0.400

Number of observations = 398
LR $\chi^2_{(78)} = 237.77$
$\Pr ob > \chi^2 = 0$
log likelihood = -156.0011
Pseudo R^2 = 0.4325

** Significant at 1% level.
* Significant at 5% level
a Significant at 10% level,
b Significant at 20% level.

Use of rice residue as feed (FEED) and fuel (FUEL) were both significantly associated with decrease in probability of rice residue burning by 55.30 percent and 23.35 percent, respectively. Thus the farmers can reduce the adoption of burning practice by utilizing the residue for domestic purposes.

The probability of burning of rice residue was increased by 29.45 percent with the intention of the producers to reduce turnaround time between harvesting of rice and sowing of wheat (REDTUURN). Delay in sowing of wheat reduces its yield by 30 kg/day (Akhtar et.al., 1992) and in order to sow on time farmers are burning residue to clear the field. Intention of the farmers to burn rice residue for the convenient use of farm machinery had positive significant impact on the probability of residue burning by 41.49 percent. Thus farmers used burning practice for the convenient use of farm machinery for the preparation of fields for the wheat crop. Thus the reduction of turnaround time between harvesting of rice and sowing of wheat and convenient use of farm machinery demand the proper disposal of rice residue for obtaining better wheat yield.

Not surprisingly, producers in the Gujranwala district exhibited higher probability of rice residue burning than Sialkot district, the calculated change in probability was 16.53 percent. Larger farm size in Gujranwala district compared to Sialkot district probably contributed to this change.

3.2. Potential for electricity generation

If one looks at the overall area of rice allocated to different residue management practices, then the full burn method ranks as first and second rank is removal (Table 4). Some 58 percent of area under rice is fully burned, while 25 percent of rice area has full removal of residue. The remaining area is either partially burnt or a small portion is incorporated into the field. We observed a similar pattern of adoption of different residue management practices for different varieties of rice (see Table 4). The results of logit model indicate that total cost associated with the handling of residue and preparation of field for wheat crop after rice was significantly related with the increase in probability of rice residue burning. The survey results show that the total cost associated with the handling of rice residue and preparation of the wheat field after various rice residue management practices was the highest at Rs. 4585.72 for the REMV practice and the lowest at Rs. 3423.94 for the BPLP practice. The total cost was higher for RPBL, RPINC and INC by 25.56 percent, 26.51 percent and 19.68 percent, respectively, in comparison with BPLP. Thus, the burning of residue is the most economical method for handling rice residue and preparing the wheat field. Under the prevailing cost conditions, farmers will not decline in rice residue burning unless they are compensated appropriately by other measures.

Table 4: Proportion of Rice Area with Various Varieties under Different Residue Management Practices

Variety	**Area (acres)**	**Pattern of Residue Management (Percent of Total Rice Area)**				
		Complete Removal of Residue	**Removal of *pural* and Burning of Lower Parts of Rice Plant**	**Burning of *pural* and Lower Parts of Rice Plant**	**Removal of *pural* and Incorporation of Lower Parts of Rice Plant**	**Complete Incorporation**
Super Basmati	2677	25	12	59	3	1
Basmati 386	810	26	12	53	9	0
Other Varieties	303	23	12	62	3	0
All Varieties	3790	25	12	58	4	1

The proportion of the straw burnt for various varieties ranged from 53.75 to 58.12 percent for the practice of removal of *pural* and the burning of the lower parts of rice plant from 63.48 to 69.26 percent for the practice of burning the *pural* and the lower parts of the rice plant. In terms of quantity 931 and 1034 kg of rice straw per acre was burnt in these practices, respectively. On overall basis, 712 kg of rice straw per acre was burnt in the study area. Of the total surveyed respondents, 61 percent were of the view that the trend in rice residue burning was increasing although 31 percent thought it was decreasing. About eight percent thought there is no change. As reported by 46 percent and 65 percent of the respondents, respectively, the short turn-around time between the harvesting of the rice crop and the sowing of the wheat crop and inconvenience in the use of farm machinery were the major reasons for the burning of rice residue. Major reasons for not burning the residue included its use as feed for animals and for home cooking as reported by 95 percent and 24 percent of respondents, respectively.

On the basis of results of survey conducted in rice-wheat cropping system, total quantity of rice residue burnt is estimated as 1704.91 thousand tonnes. Using the same basis as used for rice–wheat cropping system, total quantity of rice residue burnt is estimated as 3106.68 thousand tonnes for Punjab and 4159.05 thousand tonnes for Pakistan, which could be used for electric power generation.

On the basis of the quantity of rice residue burnt, the potential for electric power generation is estimated as 162.51 MW, 296.13 MW and 396.44 MW for the rice–wheat cropping system, areas of Punjab and Pakistan, respectably. The power scenario in the rice–wheat cropping area and in other areas in Punjab and Pakistan is characterized by fluctuating voltage, load shedding and unreliable supply. The demand for electricity is increasing over time and is expected to increase many folds in coming years in Pakistan. Electricity is essentially required for improving health facilities, education system, living standard and for other economic activities including running of tubewells for meeting the water requirements of rice and other crop. Major quantity of the demand is met through fossil fuels. Diminishing fuel reserves, mounting oil prices accompanied by Green House Gases emission from burning of fossil fuels resulting in global environment problems demand to look for renewable energy for meeting future energy requirement. Thus significant part of future energy must be met from renewable energy sources to meet the rising demand and to reduce Green House Gases emission. According to World Bioenergy Association (2010), reasonable and sustainable use of world biomass energy can meet energy demand globally. The European Commission has set an overall target of 20 percent share in renewable energy and a 10 percent share of renewable energy in transport for the year 2020 (Dam and Junginger, 2011). U.S. Department of energy has set a target that biomass will supply energy equivalent to 30 percent of current petroleum consumption (Fengxiang et. al., 2011). Similarly, targets have been fixed by Romania (Scarlate et. al., 2011) and Australia (Herr and Dunlop, 2011). Demirbas (2011) has reported that biomass energy can meet half of the present global energy consumption by the year 2050. Keeping in view, the haulage cost associated with rice crop residue, installation of crop residue biomass power plants at the village level would be an attractive option for improving electricity supply. Such decentralized units can benefit the rural population in many ways. Firstly, it can generate income to farmers from rice residue which is presently being burnt by them. Secondly, it generates employment through involvement of rural population in collection, transport, loading and other activities. Thirdly, decentralized power units at the village level can stimulate economic activities through assured power supply (Hiloidhari and Baruah, 2011).

4. Conclusions

This paper addresses two very important issues i.e. why farmer's burn rice residue and what is the potential of electricity generation from the residue being burnt. Burning of rice crop residue can have significant effect on the yield of crops, physical properties of soil and environment. The results obtained by using logit model provide policy makers with additional insight into the relations between the adoption of rice residue burning practice and the various factors which influence its adoption. There will not be significant decline in rice residue burning under prevailing government policies as the other practices are costly in terms of handling of rice residue and preparation of wheat field after rice. Application of choice logit model has identified farming experience, farm size, farmer's caste, soil type, tenure type, animal strength, use of residue as feed and fuel, cost of preparation of wheat field after rice, reduction in turnaround time between harvesting of rice and sowing of wheat, convenience in use of farm machinery, availability of machinery for incorporation and geographic location of farm as among the key explanatory variables of rice crop residue burning adoption.

The present study also attempted to estimate the quantity of burnt rice residue which could be used for the generation of electricity. The results indicate that 58 percent of area under rice is fully burnt, while in case of 12 percent area, pural is removed and lower parts of rice plant are burnt. The proportion of the straw burnt ranged from 53.75 to 58.12 of the total straw produced for various varieties of rice when the farmer removed the pural and burnt the lower parts of rice plant, while this proportion varied from 63.48 to 69.26 percent when the farmers burnt both pural and lower parts of rice plant. On overall basis, 712 kg per acre of rice straw was burnt in the study area. The overall quantity of rice straw burnt is estimated to be 1704.91 thousand tonnes for the rice–wheat cropping system area, 3106.68 thousand tonnes for Punjab and 4159.05 thousand tonnes for Pakistan. The rice straw burnt has the potential to generate 162.51 MW, 296.13 MW and 396.44 MW electric powers in the rice–wheat cropping system area, Punjab and Pakistan, respectively. In order to minimize the cost of haulage of rice straw, installation of decentralized power plants at village level would be a good option. Further, use of rice crop residue as an energy source can help in reducing foreign exchange requirements as four kg of crop residue can substitute one litter of furnace oil or 1 m^3 of natural gas (Dubey et. al.). Moreover, power generation from crop residues would be a source of income for the farmers from the rice residue along with generation of additional employment opportunities and economic activities on sustainable basis.

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