# Burning of Crop Residue and its Potential for Electricity Generation

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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 burning decision of rice residue are investigated through logit model. A number of factors had significant effects on the burning decision of crop residue. These included farming experience of the farmer, Rajput caste, farm size, owner operated farm, owner-cum-tenants operated farm, silty loam soil type, livestock strength, total cost associated with the handling of residue and preparation of wheat field after rice, availability of farm machinery for incorporation, use of residue as feed for animals, use of residue as fuel, intention of the respondent to reduce turnaround time between harvesting of rice and sowing of wheat, convenience in use of farm machinery after burning of residue and the geographic location of farm. The overall quantity of rice straw burnt is estimated to be 1704.91 thousand tonnes in the rice-wheat cropping areas 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 along with generation of additional employment opportunities and economic activities on sustainable basis. In order to minimise the cost of haulage of rice straw, installation of decentralised 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 for import of furnace oil.

*JEL Classification:* O44, Q12, Q16, Q42, Q48
*Keywords:* Bioenergy, Crop Residue, Electricity, Energy, Growth, Rice

## 1. INTRODUCTION

Most of the villages in Punjab have inadequate electricity supply. These villages have to face electricity shut downs because of severe electricity shortage in Pakistan. In Pakistan, household sector was the largest consumer of electricity with a share of 46.5 percent while major sources of electricity generation were fossil fuel (64.1 percent) and hydro (31.9 percent) during 2011-12 [Pakistan (2013)]. Due to political reasons, Government of Pakistan is not developing new hydro resources for electricity generation but generates electricity through burning of fossil fuel, which produces 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.

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Bioenergy accounts for about 10 percent of total energy consumption in the world 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 teragram (tg) of biomass are burnt in Asia and out of which 250 tg are 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 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); 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 to 15 percent and enhance atmospheric solar heating by as much as 50 percent. 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)] it also results in the loss of plant nutrients [Biederbeck, *et al.* (1980); Gupta, *et al.* (2004); Heard, *et al.* (2006); IRRI-CIMMYT Alliance Cereal Knowledge Bank (2007)] in addition, it also creates 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 and crop yield [Sharma, *et al.* (1985); Sidhu and Beri (1989); Ganwar, *et al.* (2006); Hartley and Kessel (2005); Kessel and Horwath; Prasad, *et al.* (1999); Hooker, *et al.* (1982); Bhatnagar, *et al.* (1983); Garg (2008); Surekha, *et al.* (2006); 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 a dominant source of residue and about 0.17 million tonnes of residue biomass has a potential to produce about 17MW power. According to them, decentralised 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 production, bio-energy and climate should be better understood in order to estimate the realistic 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 $3.70 \times 10^{10}$ J/ha/year under traditional methods, $7.93 \times 10^{10}$ J under labour intensive and $8.36 \times 10^{10}$ J under capital intensive methods. 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 its major component. 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 can be used for energy generation besides feeding of animals and improvement of soil fertility. Moreover, environmental advantage connected with burning of residue for electricity generation can be revealed from the fact that this usage does not compete 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 decentralised electricity supply system based on crop residue in rural areas. Likewise, Karaj, *et al.* (2010) analysed 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 technical 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. Open field burning of residue has adverse impact on the soil fertility [Malhi and Kutcher (2007)] and 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 electricity shortage problem. As in Pakistan, no comprehensive study has been carried out to identify the factors influencing the rice crop residue burning decision by the farmers and the potential of burnt rice residue for electricity generation, so this study is conducted to answer this question. The specific objectives of the study are:

(1) To determine the factors, which influence farmers to make decision of burning of rice crop residue,  and
(2) To find out the quantity of electricity that can be produced by using the rice straw that is currently being burnt.

The rest of paper is organised as follows. Section 2 describes the methodology along with model specification and description of data set. Section three discusses the results of models and key determinants of the rice crop residue burning decision by the farmers along with potential of the burnt residue for electricity generation. Last section deals with summary and suggestions for the generation of electricity.

## 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 electricity that can be generated from the residue, which 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 (i.e. complete removal/incorporation) residue management practice essentially involves a choice by the farmer. Binary choice models are more appropriate when a choice is made between the two alternatives [Judge, *et al.* (1980); Pindyck and Rubinfeld (2000)]. 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 and Kramer (1985)]. Problems of the linear probability model can be overcome through the monotonic transformation (Probit or logit specification), which guarantees that predictions lie in the unit interval [Capps and Kramer (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 maximisation. According to this rule, farmer $i$ selects the alternative from the choice set that maximises 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,

$\varepsilon_{ij}$ 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.

$$U_{i1} \geq U_{i2} \quad \text{or} \quad U_{i1} + \varepsilon_{i1} \geq U_{i2} + \varepsilon_{i2}$$

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 of the difference in stochastic utility of choice 1 and 2 being less than or equal to the difference in systematic utility of choice 1 and 2. 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 ($Z_i$) summarising a set of farmer attributes, which 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 $\beta$ 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 $\beta_k$ is the $k$th element of the parameter vector $\beta$.

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 burns 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 analyse the decision of rice residue burning:

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

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 |
| K2EXP | Farming experience of farmer in years |
| PRIM | 1 if farming is the primary occupation; 0 otherwise |
| UPMAT | 1 if educational level of farmer is up to 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 if 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 |
| INSECT | 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 were burnt (RPBL), area from which pural was removed and lower parts of stem were burnt (BPLP), area from which pural was removed and lower parts of stem were incorporated (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 weighting 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  steam and  further 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 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 and Baruah (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 [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 units (PSU). Farmers within the PSUs were taken as secondary sampling units. 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 transportation cost per acre of rice residue is Rs 485.84 (Rs 104 = 1 US$).

Table 2

*Descriptive Statistics for the Variables Used in Logit Analysis*

| 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 |
| INSECT | 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 |

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 fourteen variables out of twenty six variables included in the model. These factors were: (a) Farming experience of the farmer (EXP), (b) Rajput caste (RAJPUT), (c) Farm size (SIZE), (d) Farmer is owner operator (OWNER), (e) Farmer is owner-cum-tenant (OWNCT), (f) Soil type is silty loam (SILTL), (g) livestock strength on the farm (ANIMAL), (h) Total cost associated with the handling of the residue and preparation of wheat field after rice (TCBURN), (i) Farm k2 machinery availability for incorporation (MACH), (j) Use of residue as feed for animals (FEED), (k) Use of residue as fuel (FUEL), (l) Intention of the respondent to reduce turnaround time between harvesting of rice and sowing of wheat (REDTURN), (m) Burning of residue results in convenient use of farm machinery (CONMACH) and (n) The geographic location of farm in Gujranwala (GUJRAN) district.

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 |
| INSECT | 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 |

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 improves 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  is due to substantial and  ready 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 [Surekha, *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 stop rice residue burning practice 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.

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 utilising 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 and 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 difference.

## 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 removal ranks as second (Table 4). 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).

Table 4

*Proportion of Rice Area with Various Varieties under Different Residue Management Practices*

| | | Pattern of Residue Management (Percent of Total Rice Area) | | | | |
|---|---|---|---|---|---|---|
| Variety | Area (Acres) | 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 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 stop rice residue burning unless they are compensated appropriately by other measures.

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 kg and 1034 kg of rice straw per acre was burnt under 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 at 1704.91 thousand tonnes. Using same basis as used for rice-wheat cropping system, total quantity of rice residue burnt is estimated at 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 characterised by fluctuating voltage, load shedding and unreliable supply. However, demand for electricity is increasing over time and is expected to increase many folds in coming years in Pakistan. Electricity is 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 crops. Major part of the demand is met through fossil fuels. Diminishing fuel reserves, mounting oil prices and 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 of 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 [Scarlat, *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. In view of 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 decentralised units can benefit the rural population in many ways. First, these can generate income for farmers from rice residue, which is presently being burnt by them. Second, these can generate employment through involvement of rural population in collection, transport, loading and other activities. Third, decentralised 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 farmers burn rice residue and what is the potential of electricity generation from the residue being burnt? Burning of rice crop residue has 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 key explanatory variables of rice crop residue burning decision.

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 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 percent 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 power in the rice-wheat cropping system area, Punjab and Pakistan, respectively. In order to minimise the cost of haulage of rice straw, installation of decentralised 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 one $m^3$ 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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