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Study on the supply capacity of crop residue as energy in rural areas of Heilongjiang province of China

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ABSTRACT

Heilongjiang is the most northeastern province of China. The climate of Heilongjiang consists of very cold winters, leading to large energy demands for space heating by local residents. Rich food crop yields in Heilongjiang results in large amounts of crop residues. To fully accommodate rural energy demand and facilitate the effective utilization of crop residues, this study builds a mathematical model of supply capacity of crop residues as energy, then, based on the data from a field survey and literature review, calculates the local annual effective heat demands for living, the supply rates for effective heat of different crop residue utilization patterns, and the supply capacities of crop residues as energy in rural areas of Heilongjiang. Results show that the supply capacity of traditional direct burning of crop residues is less than 1, indicating that direct burning of crop residues cannot fully supply rural living heat demands. The supply capacity of densification is more than 1.6, indicating that introducing densification can not only achieve full supply for rural living heat demands, but also result in a large proportion of crop residues remaining for other uses. Because part of the crop residues is converted to products other than gas, dry distillation can only supply 55% of the rural living heat demands. Introducing efficient technologies of crop residue utilization for energy in rural areas of Heilongjiang can make the available amount of energy from crop residues larger than the amount of energy demand. This study found that the combination of densification and dry distillation of crop residues can be used as a high-efficiency centralized supplement of living heat, achieving multiple benefits such as use of alternatives to fossil fuel energy, economic development, environment protection, and improvement in quality of life.

Contents

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Nomenclature

q_c/q_h	effective heat index for cooking/heating, MJ/(capita a) and MJ/(m^2 a)
m_c/m_h	annual consumption of a type of cooking/heating fuel, (kg/a)
v_c/v_h	calorific value of a type of cooking/heating fuel, (MJ/kg)
η_c/η_h	thermal efficiency of cooking/heating
n	household population, (capita)
A	residential area, (m^2)
Q_c/Q_h	annual demanded effective heat of cooking/heating, (MJ/a)
N	rural population, (capita)
a	rural residential area per capita, (m^2/capita)
r_c/r_h	supply rate for effective heat of cooking/heating, (MJ/kg)
e	material utilizing coefficient, (kg/kg or m^3/kg)
v	calorific value of fuel processed by crop residues, (MJ/kg or MJ/m^3)
e'	net material utilizing coefficient of dry distillation, (m^3/kg)
$p_c/p_v/p_t$	material utilizing coefficients of charcoal, tar, and pyroligneous acid, (kg/kg)
C	supply capacity of crop residues as energy
M_{avl}	annual available amount of crop residues, (kg/a)
$M_{dmd.c}/M_{dmd.h}$	annual demand amount of crop residues for cooking/heating, (kg/a)
Y	annual grain yield, (kg/a)
s	residue production ratio
F	sown area of a crop, (hm^2)
δ	suitable annual recycling amount of a crop, (kg/(hm^2 a))

1. Introduction

Heilongjiang is the northernmost and easternmost province in China, with an area of 473,000 km^2 and a population of more than 38 million, of which nearly a half is rural. The climate of Heilongjiang is classified as a temperate continental monsoon climate; therefore, Heilongjiang is very cold in the winter, leading to large energy demands for space heating by local residents. In Heilongjiang, more than 90% of the cultivated fields are sown with rice, corn, soybean, and wheat. The provincial crop yield per capita is the highest in China [1]; thus, the per capita amount of crop residues in rural areas of Heilongjiang is also large. Due to the coexistence of large heating fuel demands and large crop residue yields in Heilongjiang, it is necessary to judge whether the crop residues could be used to fully supply the heating demands of local rural residents.

Cooking and heating in cold regions are essential energy-using activities for basic living needs. Because both the activities use heat from burning fuels, this energy can be called “living heat.” In rural areas of Heilongjiang, living heat accounts for the main proportion of energy consumption of residents [2]. Recently, most of the rural households have been directly burning crop residues for cooking and heating. Given the cold winters in Heilongjiang and the low efficiency of direct burning of crop residues, the amount of crop residues used as heating fuel in rural households is large, leading to shortages of crop residues in some rural regions. Given the shortcomings in direct burning of crop residues of short combustion duration, low flame temperature, indoor environmental pollution, and the costs attributed to the time and effort needed for fuel collecting and feeding, some richer rural residents would rather pay for fossil fuels, such as coal and liquefied petroleum gas (LPG), and abandon the use of free renewable crop residues, thus leading to the inefficient use and surplus of crop residues in the region.

To improve the performance of crop residues as domestic fuel and to make full and efficient use of crop residues in rural areas, researchers in China have been studying many kinds of technologies to utilize crop residues as energy [3]. Considering objective conditions such as the local climate and crop species, it has been found that suitable technologies of crop residue utilization as energy in Heilongjiang are densification and dry distillation. The densification of crop residues refers to pressing crop residues into pellets with a higher density, improving the energy density and combustion efficiency, thus making them easy to transport, store, and use. The dry distillation of crop residues refers to heating crop residues in the absence of oxygen, which produces charcoal, tar, pyroligneous acid, and gas. The quality of the gas produced through distillation meets the requirement for urban gas in China. The other three products of distillation (charcoal, tar, and pyroligneous acid) can be sold as commodities to achieve economic benefits.

To achieve full and efficient use of crop residues in a region, the first and foremost task is to assess whether the available amount of local crop residues can meet the region's actual needs. Previous research has examined the available amount of crop residues for various regions. Scarlat et al. provided an assessment of the amount of available crop residues for bioenergy production in the European Union (EU) [4]. Scarlat et al. [4] found large spatial and temporal variations of available crop residues within EU nations and determined that the variation in available crop resides might eventually result in shortages of the biomass supply. Cui et al. and Bi et al. estimated the crop residue resources of China using two different methods [5,6]. The results included the total amount and main types of crop residues in China, and the spatial distribution of crop residues that can be utilized as energy. Other previous research has studied in more depth the feasibility of crop residue utilization technologies based on the estimation of the regional available amount of crop residues. Some of these studies involved collecting statistical information or conducting investigations to assess and predict the available amount and utilization status of crop residues in some regions, which provided developmental targets and effective ways for crop residue utilization [7–,8,9]. Others studies estimated the types, yields, distributions, and other availability characteristics of crop residues in a nation or region through the use of GIS and remote sensing technology, and then discussed the local feasibility of some particular crop residue utilization technologies such as crop residue power plants, bioethanol, and densification [10–15].

The existing studies discussed above have resulted in great improvements in crop residue utilization. However, these existing studies have generally focused on the available amount of crop residues but gave simple estimations, instead of in-depth studies, on the actual demand of crop residues. Without an official index of rural living heat, it is hard to estimate the demand; therefore, in China, there are no detailed studies on crop residue supply capacity based on the local demand of living heat.

This study defines “effective heat” as the actual amount of heat received by heat consumers, “supply rate for effective heat” as the amount of effective heat for living that is supplied by per unit crop residues as energy with a crop residue utilization technology, and