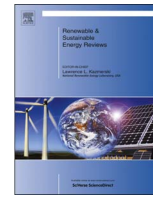
Renewable and Sustainable Energy Reviews 67 (2017) 1153–1161

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Assessment of bioenergy development potential and its environmental impact for rural household energy consumption: A case study in Shandong, China

Zhixiang Jiang [a], Yanhui Dai [b], Xianxiang Luo [b,c], Guocheng Liu [b], Hefang Wang [b], Hao Zheng [b,c,*], Zhenyu Wang [b,c,**]

[a] College of Environmental Science and Engineering, Qingdao University, Qingdao 266071, China
[b] College of Environmental Science and Engineering, Ocean University of China, Qingdao 266100, China
[c] Laboratory for Marine Ecology and Environmental Science, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266071, China

ARTICLE INFO

Article history:
Received 20 April 2016
Accepted 18 September 2016

Keywords:
Rural household energy consumption
Pollutant emission
Modern bioenergy
Emission reduction potential

ABSTRACT

The status and changes of the rural household energy consumption (RHEC) and its pollutants emission in Shandong province, China, from 1995 to 2010 were assessed, as well as the reductions of the air pollutants by developing modern bioenergy (MBE). The results indicated that the RHEC significantly increased with annual growth rate of 1.04% during the study period, and significantly changed from the traditional energy use pattern to the commercial energy use pattern. The income effect (ΔRE_{ri}^{t}) was identified as the critical factor responsible for the increased RHEC, while the energy intensity effect (ΔRE_{ei}^{t}) and the population effect (ΔRE_{rp}^{t}) were the dominant factors responsible for the decreased RHEC. Correspondingly, total emissions of the majority pollutants including CO_2, particulate matters (PMs), NO_x and SO_2 significantly increased with increasing RHEC, and positively correlated with the proportion of commercial energy (*PCE*) used in RHEC ($r = 0.821$–0.992, $P < 0.05$). In addition, CO emission showed a slight decreasing tendency in the same period. Based on the status of RHEC in 2010, the total development potential of MBE can reach up to 11.0×10^6 tce, thus the emissions of CO_2, CO, PMs and SO_2 can be reduced by 64.8%, 90.6%, 78.7% and 64.2%, respectively. Unfortunately, the emission of NO_x will increase by 31.8%, which is mainly due to the biomass-fired electricity rather than the coal-fired electricity. These results indicated that multiple benefits could be achieved through using the CS feedstock to develop the MBE products for RHEC.

Contents

* Corresponding author at: College of Environmental Science and Engineering, Ocean University of China, Qingdao 266100, China.
** Corresponding author.
E-mail addresses: zhenghao2013@ouc.edu.cn (H. Zheng), wang0628@ouc.edu.cn (Z. Wang).

http://dx.doi.org/10.1016/j.rser.2016.09.085
1364-0321/

1. Introduction

With the rapid development of China's rural area economic, the energy poverty and environmental issues (e.g., atmospheric contamination) resulted from energy consumption have become the limited factors for the sustainable development of rural household energy [1]. Statistically, the energy consumption by rural residents in China rose from 2.80×10^8 tce in 2001 to 3.35×10^8 tce in 2008, and the corresponding amount of CO_2 emission increased from 1.52×10^8 t to 2.83×10^8 t, due to the fast growth of the commercial energy consumption [2]. The percentages of commercial energy including coal (CA), liquefied petroleum gas (LPG) and electricity (EC) in the total rural household energy consumption (RHEC) greatly increased from 17.1% in 2001 to 33.9% in 2012 [2,3]. Currently, the traditional bioenergy (TBE) including crop straw (CS) and fuelwood (FW) is still dominant in the RHEC, and accounted for 60% of the total energy consumption in 2012 [3]. Although CS and FW are the carbon-neutral and renewable fuels, the traditional consumption pattern leads to serious problems [4] such as low utilization efficiency (e.g., 15% for CS), environmental pollutions (e.g., water and air pollution) and human diseases because of the released pollutants (e.g., PAHs, dioxin) [5–9]. The consumption of the high-quality modern bioenergy (MBE) (e.g., biogas (BG), biomass briquettes (BB)) only accounted for 3% of the total energy consumption [3]. Therefore, the rural area become an important source of greenhouse gases (GHGs) and air pollutants emissions in China [10]. Many studies have been conducted to reveal the law of RHEC development [4,11,12] and the relationship between air pollutants emission and RHEC [13] in order to develop more effective and feasible strategies to meet the energy demand and solve the emission issues together. The development of MBE is a promising alternative way using abundant of CS resource in the rural area.

The MBE has become one of the energy alternatives with the fastest growth rate among the renewable energy resources in China [14], which is especially promoted by the "*Medium and Long-term Development Program for Renewable Energy*" issued by China in 2007. Generally, the main MBE technologies in China include biogas (BG), biomass briquettes (BB), biomass electricity and biomass liquid fuels [14]. Facing the increasing stress of energy demand and the tremendous development potential of MBE, more and more attentions have been paid on MBE by scientists and policy makers [14,15]. Correspondingly, extensive studies have been conducted to investigate the development potential and spatial distribution of MBE from different biomass resources (e.g., CS, FW, manure) [15,16], the environment performance (e.g., air pollutant emission) of different MBE technologies [17–20] or pattern [21], and the MBE policy [1,22,23] in rural China. These results showed that there was enormous energy development potential of MBE in China's rural area due to the large abundant of biomass resources, which can be supplied sustainably and thus can reduce carbon emissions because of the decreased consumption of fossil fuel due to the substitution by MBE. However, most of these studies only focused on carbon emissions during the energy consumption, but other air pollutants (e.g., SO_2, PMs and NO_x) were ignored. Therefore, more studies should be conducted to assess the emissions of the neglectful air pollutants including CO, SO_2, PMs and NO_x, as well as CO_2 during the consumption of MBE simultaneously.

Shandong, one of the biggest agricultural provinces in China, has the higher level of economics development and huge scale of population in rural area. According to the China Statistics Bureau [24], Shandong had the third largest GDP in China and had over 4.4 million residents in rural area. Taking Shandong as a case to study the changes of RHEC and its pollutants emission, as well as the reduction of pollutants emission by developing the MBE, the results can be used as an important reference for other regions of northern China.

To our best knowledge, the investigation of air pollutants emissions including not only CO_2 but also CO, SO_2, PMs and NO_x from the development of MBE in the whole rural area in Shandong has received much less attention. To address this knowledge gap, the following questions were investigated in the present study: 1) What is the characters of RHEC and the corresponding emissions of air pollutants, and what are the dominant factors affected the alteration of RHEC? 2) How does the alteration of the structure of the RHEC impact on the emissions of the air pollutants? 3) How much are the development potential of MBE based on the status of RHEC and the reduction potential of the different pollutants emissions?

2. Methodology

2.1. Definition of the character indices of RHEC and pollutants emissions

According to previous studies, different character indices of RHEC had been selected to analysis the status and evolution of the regional RHEC during a specific historic period. These indices can be divided into four groups: the composite indices [2,10], the per capita indices [25], the structural indices [12,25] and the energy consumption practices indices [26]. The character indices used to analysis the change of RHEC and pollutants emissions in this paper are listed as follow:

The character indices of RHEC:

$$TEC = \sum_i M_i \tag{1}$$

$$TEEC = \sum_i M_i \times e_i \tag{2}$$

$$pcEC = \frac{TCE}{P} \times 1000 \tag{3}$$

$$pcEEC = \frac{TEEC}{P} \times 1000 \tag{4}$$

$$PCE = \frac{\sum_i CE_i}{TEC} \tag{5}$$

$$PCEE = \frac{\sum_i CE_i \times e_i}{TEEC} \tag{6}$$

The character indices of pollutants emissions: