Applied Energy 158 (2015) 178–189

Contents lists available at ScienceDirect

Applied Energy

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

Dynamic integrated assessment of bioenergy technologies for energy production utilizing agricultural residues: An input–output approach

Junnian Song [a,*], Wei Yang [b], Yoshiro Higano [a], Xian'en Wang [b]

[a] Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Japan
[b] College of Environment and Resources, Jilin University, 2699 Qianjin Street, Changchun 130012, China

HIGHLIGHTS

- A dynamic input–output model is developed with bioenergy technologies complemented.
- Availability of agricultural residues for bioenergy technologies is evaluated.
- Trends in electricity and biofuel production are simulated dynamically.
- Net profit and GHG mitigation contribution of bioenergy technologies are assessed.
- Combustion power generation and briquette fuel are more advantageous.

ARTICLE INFO

Article history:
Received 5 June 2015
Received in revised form 6 August 2015
Accepted 12 August 2015

Keywords:
Bioenergy technologies
Agricultural residues
Input–output
Industrialization
Power generation
Biofuels

ABSTRACT

In order to facilitate regional agricultural residue utilization for energy production through bioenergy technologies, a dynamic input–output model is developed to estimate and assess the energy, economic and environmental performances of industrialization of five bioenergy technologies within a 15-year time horizon. Electricity and solid, gaseous and liquid biofuels are energy products of bioenergy technologies. Bioenergy technologies are complemented into regional input–output framework and combined with socioeconomic activities aided by their bottom-up economic and energy parameters. The simulation results for the target area indicate that the agricultural residues available for bioenergy technologies could amount to 55.16 million t, facilitating to 8.38 million t coal-equivalent bioenergy production by 2025. A 3.1% net reduction in accumulative greenhouse gas emission compared with the "business as usual" case could be achieved owing to substitution of fossil energy with electricity and biofuels produced by bioenergy technologies. From energy production, economic benefits and greenhouse gas mitigation three aspects integratedly, direct-combustion power generation and briquette fuel are more advantageous in the target area. The quantified energy, economic and environmental performances of bioenergy technologies are expected to give recommendations for their industrial development.

1. Introduction

More and more researchers are motivated by increasing energy demand and related environmental concerns to discover sustainable ways of energy production. A reduction of greenhouse gas (GHG) emission and socioeconomic benefits of bioenergy utilization are recognized as the drivers for substitution of conventional fossil energy with bioenergy, considering the prospects of long-term inadequacy and adverse environmental impacts of fossil energy [1,2]. Worldwide grain production has observably increased due to population growth and industrialization, contributing to generating a considerable amount of agricultural residues (ARs) [3]. ARs are identified as reliable and exploitable bioresource feedstock for energy production to support decarbonization without threatening food security or affecting land use [4]. Once converted by bioenergy technologies (BTs) to produce electricity and solid, liquid and gaseous biofuels, the substantial potential of ARs to contribute to energy production diversification and GHG mitigation can be highlighted.

Abbreviations: GHG, greenhouse gas; ARs, agricultural residues; BTs, bioenergy technologies; I–O, input–output; BPs, bioenergy projects; BIs, bioenergy industries; GIs, general industries; FIs, fossil energy industries; CNY, Chinese yuan; tce, tons of standard coal-equivalent; NVP, net present value; PBP, payback period; PIR, profit–investment ratio; ANP, accumulative net profit.

* Corresponding author at: F513 Agricultural and Forestry Sciences Building, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8572, Japan. Tel.: +81 8033653120; fax: +81 298537221.

E-mail address: duliry@163.com (J. Song).

http://dx.doi.org/10.1016/j.apenergy.2015.08.030
0306-2619/

Nomenclature

Subscripts and superscripts

1	general industries (GIs)
2	fossil energy industries (FIs)
3	bioenergy industries (BIs)
e	energy industries (EIs)
h	household consumption
g	government consumption
m	bioenergy technologies (BT)
n	agricultural residues (AR)

Variables (In the formulas, the variables in bold denote vectors or matrices; (t) denotes an endogenous variable which has a changeable value.)

$X_i(t)$	output of industry i (i = 1,2,3,e)
A_{ij}	input coefficients from industry i to industry j (i = 1,e; j = 1,2,3)
$Y_i(t)$	final demand of industry i (i = 1,e)
ℓ	unit row vector
A_{13}^m	input coefficient from GIs to BT m
A_{e3}^m	input coefficient from EIs to BT m
C_i^m	costs of BT m corresponding to industry i (i = 1,2,3)
p^m	price of unit energy product of BT m
E^m	energy production of unit BT m
$S_s^n(t)$	the amount of AR n available for BTs
$X_I^f(t)$	output of farming industry
q^n	grain production coefficient of grain n
g^n	straw–grain ratio of grain n
λ^n	collection coefficient of AR n
φ^n	energy utilization coefficient of AR n for BTs
$S_d^m(t)$	total AR demand of BT m
d^m	AR demand coefficient of BT m (t/CNY)
X_3^m	total output of BI m
z^m	AR demand of unit BT m
w_i	GHG emission coefficient of industries and household (government) energy consumption (i = 1,2,3,h,g)
$H_i(t)$	household consumption provided by industry i (i = 1,e)
G_i	government consumption provided by industry i (i = 1,e)
$\Delta K_i(t)$	capital formation provided by industry i (i = 1,2,3,e)
$N_i(t)$	net export of industry i (i = 1,e)
$F(t)$	disposable income
y_i	income rate of industry i (i = 1,2,3)
α_i	share in total household consumption (i = 1,e)
β	household saving rate
τ_d	direct tax rate
$S_h(t)$	household saving
$S_g(t)$	government saving
τ_i	indirect tax rate of industry i (i = 1,2,3)
$Sub(t)$	total subsidies for BIs
δ_i	capital depreciation rate of industry i (i = 1,2,3)
$I_i(t)$	net investment for industry i (i = 1,2,3)
$K_i(t)$	capital stock of industry i (i = 1,2,3)
γ_i	capital production coefficient of industry i (i = 1,2,3)
v_i	added value rate of industry i (i = 1,2,3)
M^m	transportation cost of ARs for BT m
ζ	bending coefficient of roads (1.5)
ρ	average AR density in the target area (t/km^2)
c_t	unit transportation cost of ARs (CNY/(t km))
R^m	collection radius of ARs for BT m
$CI^m(t)$	cash input of BT m
$CO^m(t)$	cash output of BT m
θ	discount rate

The increasing importance of ARs has led to a number of studies to investigate the quantitative availability and sustainable potential of ARs for energy applications at regional or national level [4–6]. These information helps to estimate energy production capacity and locate bioenergy facilities based on regional AR availability [7–9]. The whole supply chain of ARs for energy applications has also been examined and optimized in some studies with focus on cost minimization, production maximization and GHG mitigation [10–12]. Besides the availability and supply chain of ARs, the economic and environmental assessments of BTs for energy production utilizing ARs have been extensively conducted. Delivand et al. [13] evaluated the economic feasibility of biomass-based combustion projects with various capacities to generate electricity from rice straw in Thailand. Nguyen et al. [14] assessed the environmental performance of biomass gasification for electricity production based on wheat straw with comparison to its alternatives such as straw-fired and fossil fuel-fired power generation. Hu et al. [15] provided a comprehensive evaluation of the potential economic, environmental and social impacts of crop straw briquette fuel with a corn stalk briquette fuel plant in China as an example. Shie et al. [16] used different scenarios to evaluate the energy balance of potential gasification technologies and limitation boundaries for fuel gas production. Wang et al. [17] carried out a UK-based environmental sustainability study on bioethanol production from wheat straw to show both the environmental advantages and disadvantages. Clare et al. [18] compared the economic viability and carbon abatement potential of biochar production via pyrolysis, with that of bioenergy production via briquetting and gasification using cost-benefit analysis and life cycle analysis. These representative cases have mostly focused on the environmental and economic performances of a specific BT adopting life cycle assessment as major quantification approach. Regional energy demand calls for energy diversity and therefore BTs including thermal, chemical, biological or combined ones to transform ARs to various energy products. How to allocate available ARs to various BTs and make environmental and economic assessments on multiple BTs as a whole have not been involved in reviewed studies.

Input–output (I–O) approach traditionally designed to study the interrelationships among different sectors in the economic system and describe the relationships between the inputs used and the outputs produced [19,20], has become a widely adopted instrument in the fields of energy [21–23] and also bioenergy [24–26]. The best tradeoffs among economic development, energy consumption and environmental impacts were investigated to achieve regional sustainability. More specifically, I–O approach has been used to analyze the industrialization of BTs and the induced impacts for elaborating regional bioenergy utilization. Malik et al. [27] constructed an economic multi-regional I–O model to make assessment on the direct and indirect impacts of producing biocrude in Australia. Yang et al. [28] analyzed the economic and employment impacts of algae-derived biodiesel industrial development in China based on an I–O model. However, the assessments in these studies were conducted from a static perspective without proposing policies for future industrial development of BTs. To date, a dynamic I–O analysis of the industrialization of multiple