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Water and emissions nexus for biodiesel in Iran

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ABSTRACT

Biodiesel is an attractive renewable energy in Iran. However, the concerns for food security, emissions, and water requirement move us towards developing the analytical framework to study emission-water nexus of biodiesel via the multi objective sustainable planning of biodiesel supply chain. Here, the literature of biodiesel in Iran is comprehensively reviewed and main issues are discussed. Then, a supply chain planning model is applied to depict the optimal path ways to minimize costs, net emission, and water use in Iran during 25 years. The microalgae via open ponds and jatropha cultivation reduce the total costs and improve negative emissions. The jatropha optimizes the water use and increases negative emissions. The results indicate that the integrated management of water must be carefully considered to select optimal pathway of the environmental friendly biofuel strategies. This paper provides the optimal frame work for the policy makers to consider different aspects for the future of the biodiesel supply chain of the country.

1. Introduction

Global warming, environmental concerns, and energy security are main concerning issues of policy makers toward sustainable solutions of bioenergy, recently. Iran with annual CO_2 production of 715 million tons (Mt) in 2012 has been reported to be the 10th among the Green House Gases (GHG) producers' countries in the world [1]. Thus, the carbon-mitigation strategy within the government agenda is a necessary action. The opportunities of decreasing the GHG emission, contribution of renewables to satisfy fuel demand, increasing the security of fuel supply network, and improving waste management provide the opportunity to utilize bioenergy and convert the fossil resources in more value-added products in Iran. The present resources for bioenergy in Iran are different wastes such as sewerage, agricultural, animal, food industry, and municipal solid wastes. Also, the biodiesel has the potential to provide comparable engine performance results. There are different studies to model the bioenergy supply chain from different feedstocks. Yue et al. described a comprehensive review on the key challenges and opportunities in modeling and optimization of biomass-to-bioenergy supply chains and identified the need for future research on multi-scale modeling and optimization [2]. Aransiola et al. reviewed the various technologies for biodiesel production [3] and emphasized on the microalgae as feed stocks and indicated that the economy of this process needs improvement. Schenk et al. also emphasized the high efficiency of biodiesel production from micro algae [4].

However, this paper reviews the existing literature on the potential assessment of biodiesel production, empirical efforts, and the biodiesel supply chain planning in Iran as well. Previously, the potential and the economic aspects are explored for biodiesel in Iran as explained in the next section. The water limitations and drivers for the CO_2 mitigation strategies are of critical importance for the country. However, the environmental effects (emissions and water) along with the economic aspects should be evaluated by means of multi objective decision-making to comprehensively study the opportunities and limitations for decision makers and planners. In this work, the multi objective model for planning the supply chain of biodiesel is developed to evaluate the water-emission trades-off for the attractive biomass resources in Iran. The main contribution of the present model is to regionally plan for the biodiesel supply chain for the most attractive biomass resources considering critical environmental issues in Iran. In this regard, the water-energy-emission nexus for the biodiesel production is assessed along with the economic aspects for the country. Hence, Section 2 reviews and analyzes the state-of-the-art of the literature for the biodiesel in Iran. The key issues in the present literature have been clearly explained as well. This section is classified into potential assessment of resources, the empirical efforts, and supply chain planning according to the present literature. Section 3 describes the methodology of the present work. Section 4 explains the scenarios and different assumption for modeling the supply chain. Section 5 gives the results and discusses the main issues especially environmental concerns. Section 6 concludes the paper with some recommendations for general policies and future works.

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Nomenclature

$Al_{b,i,\tau,t}$	Land area of technology type τ for biomass type *b* in region *i* at time *t*, ha
$BA_{b,i,\tau,t}$	Available amount of biomass type b with technology type τ in region *i* at time *t*, ton
$BD_{b,i,\tau,t}$	Amount of biodiesel *b* produced through technology type τ in region *i* at time *t*, litre
$BO_{b,i,\tau,t}$	Amount of bio-oil *b* generated in pretreatment in region *i* with technology type τ at time *t*, ton
$CapHr_{\tau,yr}$	Historical capacity of refinery, liter
$CapHp_{\tau,yr}$	Historical capacity of pretreatment facility, ton
$CapNr_{\tau,t}$	New capacity of refinery, liter
$CapNp_{\tau,t}$	New capacity of pretreatment facility, ton
$CCL_{b,i,\tau,t}$	Investment cost of preparing land for cultivation biomass *b* in region *i* with technology type τ at time *t*, $/ha
$CCP_{\tau,t}$	Capital cost of pretreatment technology type τ at time *t*, $/ton bio-oil
$CCR_{\tau,t}$	Capital cost of biorefinery technology type τ at time *t*, $/liter
$CF_{b,i,\tau,t}$	Land capacity production of technology type τ for biomass type *b* in region *i* at time *t*, ton/ha
$DEM_{b,i,t}$	Demand of biodiesel *b* in region *i* at time *t*, liter
$DRD_{i,j}$	Distance from refinery in region *i* to demand zone *j*, km
$EC_{b,\tau}$	Emissions of cultivation of biomass type *b* with technology type τ, Kg CO_2 eq./ha
$EE_{b,\tau}$	Emissions of biodiesel consumption *b* in vehicle type τ, Kg CO_2 eq./liter
$EP_{b,\tau}$	Emissions from conversion unit of biomass *b* with technology type τ to bio-oil, Kg CO_2 eq./ton bio-oil
$ER_{b,\tau}$	Emissions from conversion unit of bio-oil *b* with technology type τ to biodiesel, Kg CO_2 eq./liter
$ET_{b,\tau}$	Emissions from transporting the biodiesel *b* for unit distance with transportation technology type τ, Kg CO_2 eq./km/liter
$EndP_{b,i,t}$	End products of biodiesel *b* in region *i* at time *t*, liter
$Harv_{b,i,\tau,t}$	Amount of biomass type *b* of technology type τ which is harvested from region *i* at time *t*, ton
$JC_{b,\tau}$	Number of local jobs by cultivation of biomass *b* with technology type τ, person/ha
$JH_{b,\tau}$	Number of local jobs by harvesting biomass *b* with technology type τ, person/ton
$JP_{b,\tau}$	Number of local jobs by bio-oil production units *b* with pretreatment technology type τ, person/ton bio-oil
$JR_{b,\tau}$	Number of local jobs by biodiesel biorefinery units *b* with technology refinery type τ, person/liter
$JT_{b,\tau}$	Number of local jobs by biodiesel transportation *b* with transportation technology type τ, person/km/liter
$LTT_{b,i,\tau,t}$	Conversion factor of liter to ton, ton/liter
$OCB_{b,i,t}$	Operation costs of biodiesel *b* blending in region *i* at time *t*, $/liter
$OCC_{b,i,\tau,t}$	Cultivation costs of biomass *b* in region *i* with technology type τ at time t, $/ha
$OCH_{b,i,\tau,t}$	Costs of harvesting biomass *b* in region *i* with technology type τ at time *t*, $/ton
$OCP_{b,i,\tau,t}$	Operation costs of biodiesel production *b* in pretreatment τ in region *i* at time *t*, $/ton bio-oil
$OCR_{b,i,\tau,t}$	Operation production costs of biodiesel *b* in biorefinery τ in region *i* at time *t*, $/liter
$OCT_{b,i,j,\tau,t}$	Costs of biodiesel transportation *b* from refinery in region *i* to demand zone *j* with transportation technology type τ, $/km/liter
$PC_{b,i,\tau,t}$	Potentials of cultivation of technology type τ for biomass type *b* in region *i* at time *t*
TAC	Total annualized cost, $
TE	Total emissions emitted during producing and consuming biodiesel, Kg CO_2 eq.
$TFW_{b,t}$	Total amounts of required fresh water, Kg
TJ_t	Total accrued job in each year, person
$TWC_{b,t}$	Total amounts of required water with specific quality, Kg
TW	Total amounts of required water for biodiesel refineries, Kg
$VCT_{i,j,\tau,t}$	Volume capacity for transportation of biodiesel type *b* from region *i* to region *j* with transportation mode τ at time *t, liter*
$WA_{i,t}$	Available amount of water resources in region *i* at time *t, Kg*
$WC_{b,i,\tau,t}$	Water consumption (mostly due to surface evaporation) during time *t* for cultivation of biomass *b* with technology type τ in region *i*, Kg/ha
$WCT_{i,j,\tau,t}$	Weight capacity for transportation of biodiesel type *b* from region *i* to region *j* with transportation mode τ at time *t, ton*
$WP_{b,i,\tau,t}$	Water requirements in pretreatment technology type τ to produce bio-oil *b* in region *i* at time *t*, Kg/ton bio-oil
$WR_{b,i,\tau,t}$	Water requirements in biorefinery type τ to produce biodiesel *b* in region *i* at time *t*, Kg/liter
$WSE_{i,t}$	Average water surface evaporation in each region *i*, mm/day
r	Discount rate

Greek symbol

$\alpha_{b,i,\tau,t}$	Amount of bio-oil *b* generated in the conversion of unit quantity of biomass type *b* with technology τ in region *i* at time *t*, ton bio-oil/ton biomass
$\beta_{b,i,\tau,t}$	Conversion factor of biomass to bio-oil, liter/ton bio-oil
$\gamma_{b,i,j,\tau,t}$	Transportation level percentage
$\eta_{b,i,\tau,t}$	Percentage of harvesting loss with technology of harvesting type τ of biomass type *b* in region *i* at time *t*
$\rho p_{b,i,\tau,t}$	Amounts of water resources for the conversion of unit quantity of biomass type *b* with technology τ*, Kg/ton bio-oil*
$\rho r_{b,i,\tau,t}$	Amount of water resources for the conversion of unit quantity of bio-oil type *b* with technology τ, Kg/litre

Subscripts

τ	Conversion technology
b	Final energy carrier
t	Time period
lt	Life time of each technology
yr	Time point
i,j,k	Different nodes for each region

2. An overview of biodiesel studies in Iran

This section reviews the main literature for biodiesel production in Iran. Firstly, the biomass potential to produce biodiesel is assessed. Secondly, the empirical efforts to produce biodiesel from the available resources in Iran are described. Then, the proposed supply chain models are presented. The main outcomes for the present work and future studies concludes the section.

2.1. Potential assessment in Iran

Ghobadian et al. reviewed the potentials of generating power from