Energy 66 (2014) 139–149

Contents lists available at ScienceDirect

Energy

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

Energy-economic life cycle assessment (LCA) and greenhouse gas emissions analysis of olive oil production in Iran

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ARTICLE INFO

Article history:
Received 6 December 2012
Received in revised form
20 December 2013
Accepted 26 December 2013
Available online 20 January 2014

Keywords:
Cobb–Douglass
Energy-economic analysis
Greenhouse gas emissions
Life cycle assessment
Olive oil

ABSTRACT

In this study the energy and economic flows and greenhouse gas (GHG) emissions of olive oil production in Iran were investigated in terms of a life cycle assessment with considering four main stages of agricultural olive production, olive transportation, olive oil extraction and its oil transportation to the customer centers. Data was collected from 150 olive growers in Guilan province of Iran. Results revealed that the total energy consumption through the olive oil life cycle was 20 344 MJ ha^{-1} while the mass-based allocation method results indicated that the total energy consumption was 8035 MJ ha^{-1}. The total energy output was estimated as 23 568 MJ ha^{-1}. The total GHG emissions was estimated to 1333 kg ha^{-1} (CO_2eq) while the mass-based allocation method results indicated that the total GHG emissions was 525 kg ha^{-1} (CO_2eq). The agricultural production stage ranked the first in GHG emissions among the four stages with the share of 93.81% of total GHG emissions. Results of econometric model estimation revealed that the impact of human labor, farmyard manure and electricity on olive oil yield and the impact of electricity and chemical fertilizers on GHG emissions were significantly positive.

1. Introduction

Olive (Olea *europaea*) is a Mediterranean crop that is mainly cultivated in Mediterranean countries, such as Greece, Spain, Italy, Tunisia, Portugal, Syria and Lebanon. Besides the countries around the Mediterranean Sea, there are just a few zones around the world with Mediterranean climate such as USA, Australia and north of Iran, where olive are cultivated. Spain, Greece and Italy are the three major olive and its oil producers in the world, respectively [1]. The cultivation of this crop brings two important products which are olive and its oil, and one important by-product named as olive pomace which is used for animal feedstock. Also, it's reported that olive pomace oil can be used for biodiesel production. Olive pomace oil is a non-edible by-product that comes from olive oil production process with low extraction cost [2]. Iran with 29 598 ha area harvested and 37 954 t olive production, had the twelfth place in the world production ranking in 2011 [1]. It's estimated that the harvested area will increase to 40 400 ha with 121 200 tons production in 2026 [3]. Roughly 26 provinces among 31 ones in Iran have a great potential for olive production (and increasing the harvested area) that were programmed for cultivation until 2026 [3]. However, the major olive producers in Iran are Zanjan, Guilan, Qazvin, Fars, Mazandaran and Golestan provinces, now.

Energy, economics, and environment have powerful relationship. Agriculture sector is an energy consumer and its supplier in the forms of biofuels [4]. Energy usage in agriculture sector has been developed due to an increase in population, limitation in supply of arable land and desire for an increasing standard of living [5]; therefore a comprehensive energy analysis is needed to specify which operation or input has the highest energy consumption and find the ways to optimize it. Likewise, greenhouse gas (GHG) emissions analysis is needed to determine which input has the most effect on environment and how to decrease their distractive effects. Also, due to the mutual relation between energy, economics and environment, an energy analysis must be combined with an economic and environment one. So, by applying these comprehensive analyses, the present situation can be evaluated and best management strategies can be chosen in order to optimize energy usage, protect environment and achieve sustainable development.

Extensive investigations have emerged for energy flow and econometric models of agricultural crops especially the grove crops. Rafiee et al. [6] studied the energy balance between the

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http://dx.doi.org/10.1016/j.energy.2013.12.059

Nomenclature

NPP	net primary production
GHGs	greenhouse gases
CO_2eq	CO_2 equivalent
p	required population (sample size)
N	number of producers in the target population
N_h	number of the producers in the h stratification
S_h^2	variance of the h stratification
D^2	permissible error in the sample population
d	permitted error ratio deviated from average of population
z	reliability coefficient
$\bar{x}$	mean of sample
$\bar{X}$	mean of population
US $	United States dollar
$E_{TC,MA}$	total energy consumption with mass allocation
E_1	total energy consumption for agricultural olive production stage
E_2	energy consumption for olive transportation stage
E_3	total energy consumption for olive oil extraction stage
E_4	total energy consumption for olive oil transportation to the customer centers
C_{ma}	coefficient of mass allocation of olive oil in the process
E_{el}	electricity energy
γ	water density
g	acceleration in relation to free-fall
H	total dynamic head
V_A	volume of required water for one cultivating season
η_p	pump efficiency
η_{pd}	total power conversion efficiency
E_M	machinery energy
m	mass of machine
E_P	energy required to produce the machine
t	machine used time
T	economic life time of the machine
X_{ij}	vector of inputs used in the production process
α_0	constant term
α_j	coefficients of inputs which are estimated
e_i	error term
E_{hl}	human labor energy
E_f	fuels energy
E_{cb}	chemical biocides energy
E_{cf}	chemical fertilizers energy
E_{fym}	farm yard manure energy
E_d	direct energy
E_{id}	indirect energy
E_r	renewable energy
E_{nr}	non-renewable energy
β_1	coefficients of inputs which are estimated
β_2	coefficients of inputs which are estimated
γ_1	coefficients of inputs which are estimated
γ_2	coefficients of inputs which are estimated
δ_i	coefficients of inputs which are estimated from the model
RTS	return to scale
MPP	marginal physical productivity
GM (Y)	geometric mean of yield
GM (X_j)	geometric mean of j'th input energy
σ	standard deviation

energy inputs and yield for apple production in Iran and the results indicated that the total energy input and total energy output were 42 819.25 MJ ha^{-1}and 49 857.43 MJ ha^{-1}, respectively. The results of econometric model estimation showed that the impact of electricity, chemical fertilizers, water for irrigation, human labor and farmyard manure energy inputs were significantly positive on yield. In a study conducted by Tabatabaie et al. [7], the energy consumption flow and econometric models of two plum cultivars productions in Iran was investigated. Their results revealed that the total input energy was estimated to be 168 783.94 MJ ha^{-1}and 192 652.55 MJ ha^{-1} for Shablon and Ghatreh Tala cultivars production. They also used a Cobb–Douglass production function to determine a relation between input energies and yield in both productions. The benefits to cost ratios were calculated to be 2.46 and 4.18 for Shablon and Ghatreh Tala productions, respectively.

In a comparative study, Kaltsas et al. [8] investigated the energy budget in conventional and organic olive groves in Greece and found that irrigation and fertilizer application had the highest quantity from total energy consumption in both conventional and organic olive groves. Their results also revealed that inputs of field operations as fertilizer application were significantly lower in organic olive groves, while the opposite occurred for insect trapping. Guzmán and Alonso [9] studied the energy consumption in conventional and organic olive oil production in Spain and the results showed that organic olive groves have greater energy efficiency in comparison with the conventional groves. The net primary production (NPP) was reported as ranging from 22 591 MJ ha^{-1} to 81 767 MJ ha^{-1} and imported energy consumption from 5.36 GJ ha^{-1} to 56.35 GJ ha^{-1} according to the management types and studied areas in their research.

Beside energy supply issue in agricultural crop production systems, the greenhouse gas emissions are also critical. GHGs are those that absorb infrared radiation in the atmosphere, trap the heat and warm the surface of the earth. Nowadays, global warming is one of the greatest challenges facing the world. Governments, businesses and individuals around the world are learning how to change their practices and procedures to meet this challenge by identifying the ways to reduce emissions of the GHGs which cause climate changes. GHG emissions analysis has been considered by several researchers in agricultural crop production systems. Kaltsas et al. [8] reported that organic olive groves tended to have lower GHG emissions caused by the different uses of fossil energy, in comparison with conventional ones. De Souza et al. [10] determined the GHG emissions of palm oil biofuel in terms of a life cycle assessment. Their results revealed that the total GHG emissions was about 1437 kg ha^{-1} (CO_2eq) where the agricultural crop production stage had the highest share from total and the chemical fertilizers ranked the first in GHG emissions among the inputs. Salomone and Ioppolo [11] investigated the environmental impacts of olive oil production using a life cycle assessment and proposed some critical issues that can help a local olive oil production chain with lower environmental impacts such as use of by-products as fuels or fertilizers. Pishgar-Komleh et al. [12] calculated the quantity of GHG emissions of potato production in Iran and found the total emissions of 992.88 kg ha^{-1} (CO_2eq) where, chemical fertilizers and diesel fuel had the highest portion from the total, respectively.

Although Iran has the second largest oil reserves in the Middle East and the second largest natural gas reserves in the world, primary energy demand in Iran is estimated to be increased at an average annual rate of 2.6% between 2003 and 2030, down from around 5% over the past decades [13]. Increasing domestic demand will create shortfalls in supply energy during times of peak energy demand in the future, so all the energy consumer sectors especially agriculture sector must use energy more efficiently and economically. In other side, Iran's total CO_2 emission from consumption of