Analysis of Input-Output Energy Use in Sugar Beet Production in Iran

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Abstract: This study attempted to investigate energy use of sugar beet production in Iran using time series data (1988-2008) and input-output method. The results showed that, 50.63 GJ ha⁻¹ is the average annual energy consumption to produce 28.8 tons ha⁻¹ sugar beet, net energy gain was positive (442.33 GJ ha⁻¹) and energy use in sugar beet production was efficient (Energy ratio=9.76). Among the analyzed inputs used fertilizers had the highest share in energy contribution (46.6%) followed by water (32.4%) diesel (8.12%), machinery (6.07%), labor (2.38%) and seed (1.79%). Results indicated that input energy use increased by 1.7% but fertilizers and seed energy use declined by 0.59% and 2.59% respectively. The highest growth rate of energy use was for chemicals (5.17%) followed by labor (4.32%), machinery (2.3%) and diesel (2.4%). Although energy efficiency and all other energy indices improved during the study period, sugar beet production depended largely on indirect energy (55.79 %) and the share of renewable energy in the total energy use was a miniscule (5.45%). According to the results, it is desirable to initiate policies to reduce the use of non-renewable energies, particularly chemicals and increase the energy efficiency, particularly water use efficiency in sugar beet production in Iran.

Abbreviations:
ha hectare  PTO Power Take-Off  hp horse power
AGR annual growth rate  kg Kilogram  gal gallon  L liter
GJ Giga joule  m³ cubic meter  h hour  MJ Mega joule

Key words: Energy Analysis・Energy Efficiency・Input-Output Method・Sugar Beet Production・Iran

INTRODUCTION

The agricultural sector is one of the most important contributors to Iran's economy. It accounts for almost 13% of Iran's GDP, 20% of employment, 23% of non-oil exports, 82% of domestically consumed food stuffs and 90% of raw materials used in the food processing industry [1]. The Iranian government has highlighted agriculture as a strategic sector through policies aimed at food self-sufficiency, arguing that it is a vital sector to the national economy as well as the national security [2]. Energy use in agriculture has been increasing in response to a growing population, a limited supply of arable lands and a desire for higher standards of living [3,4].

Iran spends enormous sums subsidizing energy each year ($ 40 to $100 billion a year) [1], however, these subsidies fail to achieve their objectives and energy wastage in Iran amounts to six to seven billion dollars a year [1,5,6]. As a result, the Iranian government has taken new steps to reduce fuel and energy consumption, including rationing the amount of subsidized petrol and diesel [5,6,7]. These policies have increased awareness about energy use and prompted public debates about the effects of energy use on the environment. One concern of the debate is the use of energy in agriculture [8]. Effective use of energy in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, preservation of fossil fuel resources and reductions in air pollution [9-12]. Therefore, there is an increasing interest to investigate energy use in agriculture.

Sugar beet is one of important commercial and energy use crop and 30% of global production of sugar (raw equivalent) is derived from sugar beet which is
produced commercially in forty countries [13]. In the year 2010, Iran produced 3.9 million tons of sugar beet on 99,486 hectares. According to these production levels, Iran produced 11% of sugar beet in Asia. After Turkey and China, Iran is the 3rd largest producer of sugar beet in Asia and 13th largest producer in the world [14,15]. The productivity of sugar beet is currently roughly 40 tons ha⁻¹ in Iran, a vast improvement from the 24 ton ha⁻¹ in 1990 [14,15]. However, Iran ranks 34th in sugar beet productivity in the world [13,15]. Sugar beet is grown throughout Iran under irrigated conditions and it is considered an intensive crop [14]. Sugar production in Iran is done almost exclusively through contract farming with sugar processing companies. Sugar beet production at the global level is in long-term decline, falling from a peak of 314 million tons at the end of the 1980s to 228 million tons in 2010, by a large reflection of policy reforms [13,16].

Many researchers have studied energy consumption to determine the energy efficiency of different crops in Iran [7,12,20,27,... etc]. However, there is not any specific study about sugar beet. In the region also, only one study is known to have been published by Erdal et al., (2007) who studied the energy use of sugar beet in Tokat province of Turkey [17]. Most of the previous studies have used primary data and been related to a localized study area, such as a province or a part of the country. This study used time series data at the national level to analyze the energy use in Sugar Beet Production in Iran.

**MATERIALS AND METHOD**

Time series data of inputs and output of sugar beet production at the national level were collected for the years 1988 to 2008. The study included this time period because organized and usable statistical material covering the entire country was available for this period of time. The sources of data were the Agricultural Scientific Information and Documentation Center (ASIDC) [18] of the Agricultural Ministry of Iran [14] and Statistical Centre of Iran (SCI) [19] as the most significant agricultural data banks in Iran.

Inputs used in sugar beet production were machinery, human labor, fertilizers, fuel, chemicals and seed. Output was sugar beet (beet root) as the product. Data concerning labor was given in the form of labor-day ha⁻¹ assuming 8 h of work per day [7,14,19,20,21,22,23]. As the use of animals in sugar beet production in Iran is negligible, it was assumed that human labor was the only labor used in production. The energy equivalents associated with labor vary considerably depending on the approach chosen and must be adapted to the living conditions of the study area [7,24,25]. It was assumed that the quality, as well as the type of seed during the study period was the same. Fertilizers included nitrogen (N), phosphorus (P2O5) and potassium (K2O). Organic manure and some other special fertilizers were neglected as their usage was extremely low. Chemicals were considered as herbicides, fungicides and insecticides.

It was assumed that sources of water (groundwater, surface water, etc.) and water pumps (electrical and diesel pumps) used across the country were same. Thus, the energy use of water included all energy used from the water source to the farm which covered all energy use of well drilling and water pumping. To measure the energy equivalence of water we referred to previous studies which considered 1.02 MJ per Cubic meter used water (Table 1). To calculate the consumed fuel the following equation was used:

\[
Q_{avg} = 0.06 \times 0.73 \times N_{tr} \times P_{PTO}
\]  

(1)

Where;

- \(Q_{avg}\) is average diesel consumption,
- \(N_{tr}\) is efficiency of transfer the PTO power (80%) and \(P_{PTO}\) is maximum PTO power (75 hp). The fuel coefficient in gas and diesel tractors are 0.73 and 0.06 respectively. Since most tractors used for agricultural operations in the last 25 years in Iran were two wheel drive Massey Ferguson (75 hp) with an average weight of 2500 kg, the average annual fuel consumption was calculated as; [26, 27]

\[
Q_{avg} = 0.06 \times 0.73 \times 0.80 \times 75 = 2.628 \text{ gal/h or 9.93 liter(l)}
\]

(2)

In this calculation we assumed the fuel consumption of tractors for different operations to be the same. To find the diesel consumption we used the average diesel consumption (AD), mechanization level (ML) and average required time of any operation (T) in sugar beet production (Eq. 3);

\[
\text{Annual diesel consumption} = AD \times ML \times T
\]

(3)

To assess the embodied energy in the production of machinery and tractors it is assumed that the energy consumed for the production of the tractors and machinery will depreciate during their economic life time. The economic life time for agricultural machines was taken to be 13 years [7,14]. Energy equivalent for machinery was calculated using Eq. (4) [28]:

\[
Q_{eq} = 0.06 \times 0.73 \times 0.80 \times 75 \times 0.0269 = 3.54 \text{ MJ/ton}
\]
Table 1: Energy equivalent of inputs and output in sugar beet production

<table>
<thead>
<tr>
<th>Unit</th>
<th>Energy equivalent MJ unit⁻¹</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor h</td>
<td>1.96</td>
<td>[7,17,27,30,39,37,38,39,40,41,42,43,44,48]</td>
</tr>
<tr>
<td>Machinery kg</td>
<td>62.70</td>
<td>[17,27,37,38,39,40,42,43]</td>
</tr>
<tr>
<td>Diesel L</td>
<td>56.31</td>
<td>[27,17,36,37,38,40,42,43,44]</td>
</tr>
<tr>
<td>Fertilizers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N) kg</td>
<td>66.14</td>
<td>[9,17,27,36,37,39,40,42,43,44]</td>
</tr>
<tr>
<td>Phosphorus (P₂O₅) kg</td>
<td>12.44</td>
<td>[17, 27, 36, 37, 38, 40, 42, 43, 44]</td>
</tr>
<tr>
<td>Potassium (K₂O) kg</td>
<td>11.15</td>
<td>[17,27,36,37,38,40,42,43,44]</td>
</tr>
<tr>
<td>Chemicals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insecticides kg</td>
<td>101.2</td>
<td>[17,37,38,40,43]</td>
</tr>
<tr>
<td>Fungicides kg</td>
<td>216</td>
<td>[17,37,38,40,43]</td>
</tr>
<tr>
<td>Herbicides kg</td>
<td>238</td>
<td>[17,27,37,38,40]</td>
</tr>
<tr>
<td>Water m³</td>
<td>1.02</td>
<td>[9,17,27,37,39,40,42,43]</td>
</tr>
<tr>
<td>Seed kg</td>
<td>50</td>
<td>[9,17,48]</td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Sugar beet (beet) kg</td>
<td>17.1</td>
<td>[9,17]</td>
</tr>
</tbody>
</table>

\[
ME = E \left( \frac{G}{T} \right)
\]  \hspace{1cm} (4)

Where:

ME is the machinery energy (MJh⁻¹), E (62.7 MJ kg⁻¹) is the equivalent energy for machinery production; G is the weight of machine (kg), T is the economic life of the machine (h).

In this study we assumed the harvested sugar beet (beet root) as the only output product of the plant. The total energy input is classified into direct and indirect, as well as renewable and non-renewable forms. Direct energy included labor, diesel and water (consisting of diesel fuel and electricity energy to pump the water and drill wells). While indirect energy covers machinery, seeds, chemicals and fertilizers. On the other hand, renewable energy included labor and seed. Non-renewable energy included machinery, diesel, chemicals and fertilizers [29-31].

There are a lot of variations in energy equivalents reported in literature. These variations are the result of differences in the calculation methods and in the spatial and temporal system boundaries. Energy equivalents must be adapted to local conditions (e.g. transport distances) and to changes in the manufacture of production means [7,11,32]. The energy equivalent of different inputs and outputs which are suggested by previous studies (Table 1) were used to estimate the energy values. The Energy Use Efficiency (Energy Ratio), Energy Productivity, Specific Energy (Energy Intensity) were calculated through following equations [7,20,21,33]:

\[
\text{Energy Efficiency} = \frac{\text{Energy Output (MJ ha}^{-1})}{\text{Energy Inputs (MJ ha}^{-1})}
\]  \hspace{1cm} (5)

\[
\text{Energy Productivity} = \frac{\text{Yield (kg ha}^{-1})}{\text{Energy Inputs (MJ ha}^{-1})}
\]  \hspace{1cm} (6)

\[
\text{Net Energy Gain} = \text{Energy Output (MJ ha}^{-1}) - \text{Energy Inputs (MJ ha}^{-1})
\]  \hspace{1cm} (7)

\[
\text{Specific Energy} = \frac{\text{Energy Input (MJ ha}^{-1})}{\text{Yield (kg ha}^{-1})}
\]  \hspace{1cm} (8)

**RESULT AND DISCUSSION**

**Production and Productivity:** The total area under sugar beet cultivation during the years of 1988 and 2008 fluctuated between 150,000 and 200,000 hectares (Fig. 1). In the year 2007 there was a significant decrease in the area under as it declined almost 70% compared to previous years (Fig 1). The major reason which could explain that sudden decline was the lowering of the tariff on sugar imports [34,14]. In 2006, changes occurred in the policy regarding sugar tariffs and led to more import (4 times more than 2005 and 12 times more than 2004) [34,35] and domestic sugar processing companies were not able to compete in that new market condition. Thus, the companies handed out fewer contracts for sugar beet and it led to less cultivation.

Yield per hectare for all years during the study period can be seen in Fig 1. In recent years sugar beet yield reached almost 40 tons per hectare which is the highest average productivity of sugar beet ever recorded in Iran. After 2006, most farmers who continued sugar beet production were those who were the most productive, as they were the only ones still able to make a profit.
Consequently, it is unclear whether overall sugar beet productivity rose as a result of improvements in production, or simply because less productive farmers stopped cultivating sugar beet. The average global yield is 48 ton ha$^{-1}$ and the highest productivity in the world is found in Chile where 87 ton ha$^{-1}$ is obtained [15], showing that there are opportunities to increase productivity and improve production of sugar beet in Iran.

**Energy Use (Input-Output):** Energy inputs used in sugar beet production are shown in Table 2. The average energy consumption in sugar beet production was 50.63 GJ ha$^{-1}$ per annum. It is almost 11 GJ ha$^{-1}$ more than reported input energy use of sugar beet (39.69 GJ ha$^{-1}$) by Erdal et al., (2007) [17] and 2.5 times more than reported inputs energy use (19.76 GJ ha$^{-1}$) by Hacıseferogullar et al., (2003) in their study in Turkey [48]. Tabar et al., (2010) reported 34.44 GJ ha$^{-1}$ inputs energy for selected crops which covered 80% of all cultivated area of Iran (including sugar beet) [7]. Several studies have been reported the energy use of different crops in Iran such as; 92.29 GJ ha$^{-1}$ for potato [41] 81.05 GJ ha$^{-1}$ for alfalfa [44], 68.92 and 52.57 GJ ha$^{-1}$ for corn [29,45], 45.23 GJ ha$^{-1}$ for grape [43], 42.81 GJ ha$^{-1}$ for apple [38], 39.33 GJ ha$^{-1}$ for rice [30], 30.28 GJ ha$^{-1}$ for kiwifruit [39] for 25.02 GJ ha$^{-1}$ for barley [42].

The fertilizers consumption was 589.52 kg ha$^{-1}$ and fertilizer energy by a share of 46.6% was the largest contributor to energy used in sugar production. The same result found for other crops in Iran [39-45]. Nitrogen, potassium and phosphorus consumptions were 39.74%, 5.98% and 0.92% of total inputs energy use, respectively. Erdal et al., (2007) showed fertilizers by 49.33% had the biggest share within the total inputs energy (mainly nitrogen) [17]. They also calculated 478.78 kg ha$^{-1}$ use of fertilizers in sugar beet production which was much lower than fertilizers use in Iran [17] and it shows an overuse of fertilizers in sugar beet production.

Table 2: Energy inputs and output of sugar beet production

<table>
<thead>
<tr>
<th>Unit</th>
<th>Average input use</th>
<th>Average annual Energy (GJ ha$^{-1}$)</th>
<th>Total Energy (GJ ha$^{-1}$)</th>
<th>Share in Input Energy (%)</th>
<th>Average AGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>h</td>
<td>615.24</td>
<td>1.206</td>
<td>25.32</td>
<td>2.38</td>
</tr>
<tr>
<td>Machinery</td>
<td>kg</td>
<td>49.054</td>
<td>3.076</td>
<td>64.58</td>
<td>6.07</td>
</tr>
<tr>
<td>Diesel</td>
<td>L</td>
<td>73.07</td>
<td>4.114</td>
<td>86.40</td>
<td>8.12</td>
</tr>
<tr>
<td>Fertilizers</td>
<td>kg</td>
<td>589.52</td>
<td>23.62</td>
<td>495.97</td>
<td>46.64</td>
</tr>
<tr>
<td>a. Nitrogen (N)</td>
<td>kg</td>
<td>304.25</td>
<td>20.12</td>
<td>422.58</td>
<td>39.74</td>
</tr>
<tr>
<td>b. Phosphorus (P2O5)</td>
<td>kg</td>
<td>243.43</td>
<td>3.029</td>
<td>63.59</td>
<td>5.98</td>
</tr>
<tr>
<td>c. Potassium (K2O)</td>
<td>kg</td>
<td>41.85</td>
<td>0.467</td>
<td>9.79</td>
<td>0.92</td>
</tr>
<tr>
<td>Chemicals</td>
<td>kg</td>
<td>3.86</td>
<td>0.651</td>
<td>13.66</td>
<td>1.29</td>
</tr>
<tr>
<td>a. Insecticides</td>
<td>kg</td>
<td>1.88</td>
<td>0.191</td>
<td>4.00</td>
<td>0.38</td>
</tr>
<tr>
<td>b. Fungicides</td>
<td>kg</td>
<td>0.50</td>
<td>0.108</td>
<td>2.26</td>
<td>0.21</td>
</tr>
<tr>
<td>c. Herbicides</td>
<td>kg</td>
<td>1.48</td>
<td>0.352</td>
<td>7.39</td>
<td>0.70</td>
</tr>
<tr>
<td>Water</td>
<td>m3</td>
<td>17886.19</td>
<td>16.40</td>
<td>344.56</td>
<td>32.40</td>
</tr>
<tr>
<td>Seeds</td>
<td>kg</td>
<td>19.15</td>
<td>0.906</td>
<td>19.02</td>
<td>1.79</td>
</tr>
<tr>
<td>Total input energy</td>
<td></td>
<td>50.63</td>
<td>1063.20</td>
<td>100</td>
<td>0.17</td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Sugar beet (root)</td>
<td>kg</td>
<td>28828.3</td>
<td>492.96</td>
<td>10352.24</td>
<td>-</td>
</tr>
</tbody>
</table>

Fig. 1: Cultivated area and Yield of sugar beet (1988-2008)
Table 3: Energy Indices of sugar beet production

<table>
<thead>
<tr>
<th>Energy Efficiency</th>
<th>Unit</th>
<th>Average</th>
<th>Average AGR</th>
<th>% of total input energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.76</td>
<td>2.157</td>
<td></td>
</tr>
<tr>
<td>Energy Productivity</td>
<td>kg MJ⁻¹</td>
<td>0.57</td>
<td>2.157</td>
<td></td>
</tr>
<tr>
<td>Net Energy Gain</td>
<td>MJ ha⁻¹</td>
<td>442335.53</td>
<td>2.101</td>
<td></td>
</tr>
<tr>
<td>Specific Energy</td>
<td>MJ ha⁻¹</td>
<td>1.769</td>
<td>-1.105</td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td>MJ ha⁻¹</td>
<td>21728.10</td>
<td>1.637</td>
<td>44.21</td>
</tr>
<tr>
<td>Indirect</td>
<td>MJ ha⁻¹</td>
<td>28249.79</td>
<td>-0.443</td>
<td>55.79</td>
</tr>
<tr>
<td>Renewable</td>
<td>MJ ha⁻¹</td>
<td>2111.58</td>
<td>0.969</td>
<td>5.45</td>
</tr>
<tr>
<td>Non-renewable</td>
<td>MJ ha⁻¹</td>
<td>47866.31</td>
<td>0.203</td>
<td>94.55</td>
</tr>
</tbody>
</table>

a Energy ratio  
b Energy intensity  
c including human labor, diesel and water  
d Including seed, fertilizers, chemicals and machinery  
e Including human labor and seed  
f Including diesel, chemicals, fertilizers and machinery

Water energy use, after fertilizers, took the second place of total inputs energy consumed (Table 2). Irrigation is commonly performed with furrows in Iran and so far negligible areas of agricultural land (2%) have been facilitated with efficient irrigation installations such as drip and sprinkler systems [7, 14]. It should be noted that energy use of water includes all energy used from different water sources to the farm. The share of water in total inputs energy was only 4.7% and it was not the most energy intensive input in studies which done in Turkey [17] and also Bangladesh [46] since a larger part of the crop water requirement is fulfilled by the higher annual precipitation in those countries, as compared to the mostly arid climate of Iran with an average annual precipitation below 300 mm [7,47]. However, water energy accounted for 32.04% of total energy inputs followed by diesel (8.12%), machinery (6.07%), labor (2.38%) and seed (1.79%) as shown in Table 2.

The average annual growth rate (AGR) of input energy use is given in Table 2. Energy use of all inputs increased during the study period, with the exception of fertilizers and seed. Energy use of chemicals grew by 5.17%, showing a big trend towards increased use of biocides, especially herbicides which their growth rate was 16.6% and contributed 0.7% to the total input energy use. Fungicides and insecticides followed with 8.54% and 5.33%, respectively. Labor energy use grew by 4.35%, as the second highest growth rate, followed by machinery, diesel and water energy use with 2.3%, 2.4% and 1.83% respectively (Table 2). It should be noted that diesel and machinery showed almost same growth rate because we considered the average diesel use of machinery as the diesel energy use so obviously there should be a strong relationship in their growth rate.

Fertilizer and seed energy use, showed 0.59% and 2.59% negative growth rate (Table 2). Though, the yield per hectare increased in the study period (Fig 1), seed and fertilizers energy use declined which could be a good sign address to productivity of sugar beet production in Iran. Overall total inputs energy use was 1063 GJ ha⁻¹ which gwon by 0.17% a year in the study period (Table 2).

**Energy Indices:** The energy indices of sugar beet production are given in Table 3. Average net energy gain shows more output energy than inputs energy in all years of study period and that output energy grew by an average of 2.10% a year. The average net energy gain was 442.33 GJ ha⁻¹ and showed an increasing trend, representing an improvement of net energy gain and the overall sustainability of sugar beet  production in Iran (Fig 2). Erdal et al. (2007) reported 982.09 GJ ha⁻¹ [17] and Hacseferogullar et al. (2003) calculated 358.74 GJ ha⁻¹ net energy gain for sugar beet production in their study in Turkey [48]. Tabar et al., (2010) reported 2.43 GJ ha⁻¹ net energy for selected crops [7]. Other studies reported net energy gain for different crops such as; 715.64 GJ ha⁻¹ for alfalfa [44], 174.53 GJ ha⁻¹ for grape [43], 79.45 and 51.34 GJ ha⁻¹ for corn [29,45], 46.50 GJ ha⁻¹ for barely [42], 21.00 GJ ha⁻¹ for rice [30], 16.35 GJ ha⁻¹ for kiwifruit [39], 10.71 GJ ha⁻¹ for potato [41] and 7.04 GJ ha⁻¹ for apple [38]. Thus, net energy gain of sugar beet production after alfalfa was the second highest energy gain in Iran’s agriculture (According to the published researches till now). But energy gain of sugar beet in Iran was lower than energy gain in Turkey.

The energy use efficiency (energy ratio) was 9.76 indicating that by consuming 1 unit of input energy, 9.76 units of output energy could be gained. This shows that sugar beet production in Iran is efficient. Several studies have been reported the energy efficiency for different crops such as 4.95 for grape [43], 2.59 and 2.27 for corn [29, 45], 2.86 (rain-fed) and 1.22 (irrigated) for barely [7,42],
1.88 for alfalfa [44], 1.81 for maize [7], 1.54 for kiwifruit [39], 1.53 for rice [30], 1.16 for apple [38], 1.1 and 0.85 for potato [7, 41], 1.78 for soybean, 1.32 for wheat, 0.86 for onion [7] and 1.07 as the average of energy efficiency for some selected crops in Iran [7]. Tabar et al., (2010) reported the energy efficiency of sugar beet as 1.7 [7] but it should be mentioned that in their study sugar beet was one of the selected crops and the study was not focused on sugar beet. Among all studied crops by other researchers sugar beet has the highest (9.76) energy efficiency in Iran. The energy efficiency of sugar beet production calculated by Erdal et al., (2007) was 25.75 [17], which were much higher than Iran’s sugar beet energy efficiency (9.76). However, average AGR of energy efficiency was 2.15 % (Table 3) and Fig 2 shows an increasing trend of energy efficiency in sugar beet production during the study period.

The average energy productivity was 0.57, it means 0.57 kg of sugar beet (beet root) was obtained per unit of energy used (Table 3) which was more than energy productivity of rice (0.09) [30], corn (0.28 and 0.17) [29, 45], grape (0.42) [43], apple (0.49) [38], barely (0.19) [42], potato 0.3 [41] kg MJ⁻¹ and average energy productivity for selected crops (0.27) [7]. But the energy productivity of sugar beet in Iran was almost one third of energy productivity in Turkey (1.53) [17]. Energy productivity rose from 0.46 in 1988 with an average AGR of 2.15% reflecting the productivity increased over the study period (Fig 2). Specific energy (energy intensity) is a parameter which can be used to determine the optimum intensity of land and crop management from an ecological point of view [25]. The average amount of energy required to produce 1 kg of crop was 1.77 MJ kg⁻¹, declining by 1.1% (Table 3) annually, showing less energy intensity of over the years. The reported specific energy by Erdal et al., (2007) was 0.65 for sugar beet in Turkey [17] Several studies have been reported higher specific energy for different crops in Iran such as rice (11.9) [30], barely (5.14) [42], corn (3.75 and 7.24) [29, 45], potato (3.2) [41], grape (2.4) [43], apple (2.06) [38] and some selected crops (3.69) [7].

Direct energy (including human labor, diesel and water) indirect energy use (including seed, fertilizers, chemicals and machinery) contributed 44.21% and 55.79 % of total energy use respectively. Direct to indirect energy ratio of sugar beet was 0.77 (21.73 GJ ha⁻¹/28.25 GJ ha⁻¹). This indicates that sugar beet production in Iran depends largely on indirect energy. Several studies calculated direct to indirect ratio for different crops in Iran such as; 0.19 for alfalfa [44], 0.34 for corn [29] 0.42 for kiwifruit [39], 0.76 for grape [43] and 0.97 for rice [30]. The reported direct to indirect energy ratio by Rafiee et al., (2010) and Mobtaker et al., (2010) were 1.18 for irrigated barely and 1.05 [42] for apple [38], respectively. Their reported ratios are higher than 1 and it could be because of local features of agricultural activities in Hamedan province of Iran which was the study area of both studies. Erdal et al., (2007) reported direct to indirect ratio as 0.45 for sugar beet in Turkey [17], it shows the contribution of direct energy in Iran (0.77) was higher than Turkey. Results showed during the study period indirect energy decreased and direct energy increased (Fig 3).

Renewable energy (including human labor and seed=21.11 GJ ha⁻¹) and non-renewable energy (including diesel, chemicals, fertilizers and machinery=47.87 GJ ha⁻¹) contributed 94.55% and 5.45% of total energy use in sugar beet production, respectively (Table 2). Several authors reported share of renewable energy in total energy use such as 39% for grape [43], 34.09% for barely [42], 34.07% for apple [38], 25.47 % for kiwifruit [39], 13.93 % for corn [29], 11.22 % for rice [30], 00.95% for alfalfa [44].
Tabar et al., (2010) reported 13.1% (4.51 GJ ha\(^{-1}\)) as the share of renewable energy for selected crops in Iran [7]. Erdal et al., (2007) calculated the share of renewable energy as 12.82% (5.09 GJ ha\(^{-1}\)) of total energy use in sugar beet production in Turkey. These studies show after alfalfa [44] sugar beet had the lowest share of renewable energy use compare to other crops in Iran. However, during the study period renewable and non-renewable energy use in sugar beet production in Iran showed an increasing and a decreasing trend, respectively (Fig 4).

**CONCLUSIONS**

Sugar beet production is a very sensitive agricultural activity in Iran and it significantly affected by decisions of policy makers particularly in terms of import tariff policy of sugar (section 3). Average annual energy consumption in sugar beet production was 50.63 GJ ha\(^{-1}\) and Net energy gain was positive over the study period. Among different inputs, fertilizer by annual 23.62 GJ ha\(^{-1}\) was the larger contributor to input energy use (46%) which referred to overuse (590 kg ha\(^{-1}\)) of fertilizers, mainly nitrogen (49.33% of total fertilizers) because of subsidized and cheap available fertilizers in Iran (1.3 USD per kg) [14]. In the study period fertilizer energy use declined by-0.59% annually (Table 2) which is the effect of increased price and extensional and educational efforts of agriculture administration. Water was the second major contributor of inputs energy (16.4 GJ ha\(^{-1}\)) and its share in total energy use was increased (1.83% AGR). Because of arid to semi-arid climate of Iran and low portion of efficient irrigation systems (drip and sprinkler), water is an important key factor in production of sugar beet in Iran. Therefore improvement of water energy efficiency must be considering in energy use analysis and sugar beet development programs. Chemicals energy by 5.17% AGR had the highest AGR during the study period and among chemicals; herbicides by 16% AGR was in the first place. The rapid increasing of using chemicals (Table 2) rings the caution alarm of overuse of chemicals and their environmental consequences for the policy makers and as
well as the farmers. Amount of seed energy use was declined (Table 2) which could be because of changing in cultivating method and using more efficient seeds. It should be noted that in this study we assumed the energy equivalent of all types of seeds are the same. Use of labor energy and machinery energy both increased (Table 2). Available cheap labor and illegal immigration from east border of Iran (Afghanistan) to eastern provinces which are main producers of sugar beet in Iran [7,14] led to the high growth rate (4% AGR) of contribution of labor in energy use. According to published researches till now (section 3) sugar beet had an advantage in terms of energy indices (Table 3) compare to other crops and results showed improvement and getting better energy indices for sugar beet production in Iran (Fig 2,3 and 4,Table 3). During the study period indirect energy use decreased (Fig 3) but sugar beet production depended mainly on indirect energy (55.79 %). Among its components (seeds, fertilizers, chemicals and machinery), seed and fertilizers declined and machinery and chemicals increased (Table 2). It shows more economical use of fertilizer and using more productive seeds. In the other hand, direct energy use increased and among its components (human labor, diesel, water), human labor energy by 4% average AGR had the biggest contribution which followed by diesel and water (Table 2). It shows production of sugar beet in Iran teded to labor use farming also water sources and machinery (which is strongly related to diesel use), could not grow as labor could grow over the years. Although renewable energy use increased (Fig 4, Table 3) its share in energy use compare to non-renewable energy (94.55%) was very small (5.45%) and its increased growth was almost because of increasing of human labor energy (Table 2). It shows sugar beet production significantly depends on non-renewable energy and because of externalities of non-renewable energies; policy makers should take initiate decisions to reduce the non-renewable energies use; particularly chemicals and increase energy efficiency, particularly water use efficiency in sugar beet production in Iran.

REFERENCES

15. Food and Agriculture Organization of the United Nations (FAO), 2012, Agriculture production data.


