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EmergyAnalysis of Greenhouse Cucumber Production in Sistan Region

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Abstract

In the current century, agriculture sustainability and the reduction of environmental pressure are two main objectives of the management of agro-ecosystems that is challenged by energy inefficiency. In this respect, the present study assessed one of the most important planting systems in Sistan Region by emergy analysis approach. It analyzed all inputs of greenhouse cucumber production system in Sistan including renewable inputs (sunlight, wind, rain), non-renewable inputs (net topsoil loss), and purchased inputs (machinery, fossil fuels, electricity, plastic, utility, labor, N, K, P and micro fertilizers, and chemical herbicides) and services. In this study, an emergy analysis was performed on greenhouse cucumber production system of Sistan using the data collected from a 3000-m^2 greenhouse in Zahak Agricultural Research Station (as an average representative of agricultural lands in Sistan Region). The results revealed that total emergy of greenhouse cucumber system was 1.094 × 1018seJ, and diesel fuel and labor were the main emergy consumers with the emergy consumption rates of 7.9 × 1017 and 1.92 × 1017seJ ha^{-1}, respectively. Main emergy indices including emergy yield ratio, emergy investment ratio, environmental loading ratio, and sustainability index were found to be 1.00, 2089, 4.34 and 20.23, respectively. Therefore, it is imperative to consider the optimization of highly consumed inputs, the reduction of environmental impacts, and the increase in sustainability by making changes in greenhouse structures, enhancing energy use efficiency inside the greenhouse, and mechanizing the planting, cultivating and harvesting processes in order to develop greenhouse cucumber system in Sistan.

Keywords:
greenhouse cucumber, sustainability index, emergy analysis, energy efficiency

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INTRODUCTION

Presently, the agricultural sector highly relies upon the energy consumption to meet the ever-growing food demand of the increasing population and to supply adequate food stuff (Asgharipour et al., 2012). Given the resource limitations and the adverse impact of improper exploitation of various energy resources on human health and environment, it is crucial to explore energy consumption patterns in the agricultural sector (Wang et al., 2014). Emergy analysis is a novel technique to assess the sustainability in terms of energy and precise estimation of the energy quantity and quality (Odum, 2007). Emergy is the available solar energy used directly or indirectly in the supply of a service and/or product. Emergy is also called embodied energy or energy memory and is expressed in solar emjouls (seJ) (Odum et al., 2000). In agriculture, each type of available energy possesses an emergy with a specific unit, e.g. solar emJoule, coal emJoule, and electrical emJoule. However, since solar energy is directly or indirectly the source of all energy types in biosphere, sunlight emergy (seJ) is considered the measurement unit. So, the radiation emergy per energy unit can be calculated by the relevant transformities. Higher transformity reflects more solar energy requirements for the production of inputs or services (Brown &Ulgiati, 2004).

The main advantage of emergy approach is that it enables the conversion of all natural flows and reserves and economic resources into solar energy units for a more comprehensive exploration of the system sustainability. Emergy scholars believe that the use of emergy approach in policy-making can lead to more symbiosis relationship of mankind and nature (Wang et al., 2014).

Numerous studies have reported lower energy use efficiency and productivity of the conventional agricultural practices than the natural resources-based agriculture. La Rosa et al. (2008) used emergy indicators including emergy yield, the environmental loading ratio and the index of sustainability to evaluate the red orange production in Sicily, Italy in organic and traditional production systems. They found that organic orange production uses less purchased renewable energy than traditional farming (La Rosa et al., 2008). In an assessment of soybean production in Brazil by emergy indicators, Cavalett and Ortega (2009) reported the soybean production as to be an uneconomical activity given its sale price in the marketplace and the high price of the production inputs. Four conventional farming systems in Weishan County of China were evaluated by emergy indicators and it was revealed that maize production was more sustainable in terms of energy consumption rate and environmental impacts (Zhang et al., 2012). In a comparison of three farming systems in the US including maize production system, blackberry production system, and traditional multiple crop systemdemonstrated that the traditional system had the highest sustainability and lowest environmental loading and maize system had the lowest sustainability and the highest environmental loading (Martin et al., 2006, Wang et al 2014) proved that intercropping systems were much more justifiable than the monocropping systems. In a study on the comparison of rice and vegetables production systems by emergy, energy and economic indices, Lu et al (2010). reported that although consecutive rice and vegetables production systems were more profitable in short run, alternate rice-vegetables system would be more sustainable. Wang et al. (2014) used emergy indicators to assess the small-scale production systems (smallholding) as is prevalent in northern China versus large-scale systems. They showed that the emergy efficiency of maize production in large-scale farms was 88% higher than that in small-scale farms. As well, wheat production in large farms had 41% higher emergy efficiency than that in conventional farms. They recommended that the model can be used to promote the productivity of resources for grains production in northern China. Wu et al. (2013) performed an emergy assessment on tomato production system in China and demonstrated that although traditional greenhouses using fossil fuels had more extensive area, the replacement of fossil fuels with environment-adapted renewable resources could reduce the environmental pressures and enhance system sustainability considerably. In a study in Swiss by Lagerberge, remarkable improvements were observed in emergy indicators in the integrated management of vegetables and cattle production system. He stated that the integrated system had lower emergytransformity and environmental pressure and higher sustainability than their independent production systems (Lagerberg, 1999).

Undoubtedly, the efficient use of energy in agriculture is a key to sustainable agriculture (Ghaley& Porter, 2013; Lu et al., 2010). This reflects the urgent need to revise the management and consumption patterns of agricultural biosystems (Ozkan et al., 2004). In this respect, it seems necessary to explore energy consumption pattern in order to find out high energy consuming areas in agricultural systems and evaluate energy use efficiency, environmental impacts, and their relationships with sustainable agriculture. Therefore, the examination of energy budgets of different crops would help a lot to identifying the potentials of the country. The comparison of energy productivity of various crops is a technique that can be used to prioritize the production of various crops across a certain region (BeheshtiTabar et al., 2010). The arable lands used for crop production in Sistan region cover an area of over 120,000 ha, mostly devoted to the production of wheat, barley, summer crops, alfalfa, fodder corn, grapes, and greenhouse crops. Sistan Region has recently witnessed a rapid development of greenhouse cucumber production. The objective of the present study was to evaluate the greenhouse cucumber production systems in Sistan by emergy indicators for the precise drawing of energy flow and the calculation of environmental loading and the extent of its sustainability.

METHODOLOGY

Data

In this study, an emergy analysis was performed on greenhouse cucumber production system of Sistan using the data collected from a 3000m^2 greenhouse (Table1) in Zahak Agricultural Research Station (as the average representative of agricultural lands in Sistan Region). The station is located 20 km south of Zabol to the northern part of Zehak (Lat. 30°54' N., Long. 41°61' E., Alt. 483 m.). The region has a very arid agricultural climate with long, very hot summers. The farm had loam soil with EC of 3.3 dS m^{-1} and pH of 8. They were 2-3 dS m^{-1} and 8 for irrigation water, respectively.

Greenhouse cucumber is planted in mid-August and its harvest starts 45 days later and lasts

Table 1
Inputs and Output Data of Greenhouse Cultivation System in Sistan Region

Note	Item	Unit/ha	Data
Inputs			
1	Sunlight	J	2.04×10^{13}
2	Wind	J	5.5×10^{6}
3	Water	m^3	9250
4	Topsoil		0
5	Labor	h	21760
6	Seed	g	1.1×10^{3}
7	Manure	Kg	6.0×10^{3}
8	Fuel	Lit	12.95×10^{4}
9	Machinery	Kg	4.75
10	Electricity	kwh	4.69×10^{3}
11	Plastic	g	4.00×10^{6}
12	Nitrogen	g	4.50×10^{5}
13	Phosphate	g	3.5×10^{5}
14	Potash	g	4.50×10^{5}
15	Micronutrient	g	4.80×10^{5}
16	Pesticide	g	1.00×10^{4}
17	Services	$	1.2×10^{4}
Output			
18	Cucumber yield	Kg	275000

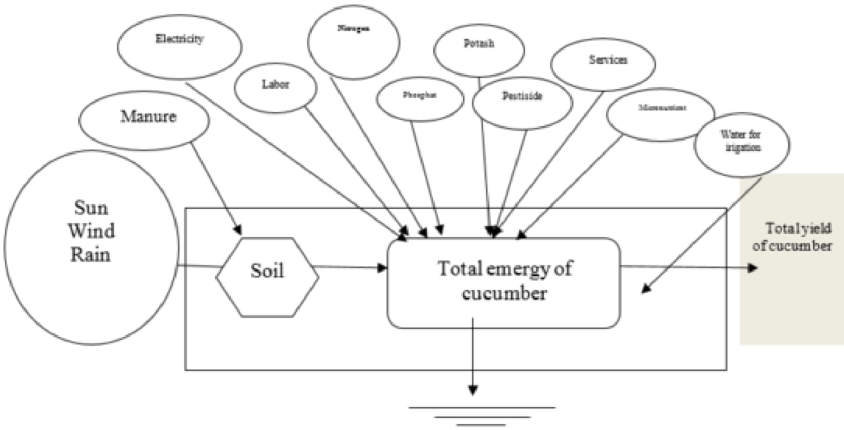

Figure 1. Emergy diagram of greenhouse cucumber

until June. Most farming operations are carried out by workers including land preparation, planting, cultivation, irrigation, pests and diseases management, fertilization, and harvesting. Chemical fertilizers are applied to stimulate the crop growth.

Emergy analysis technique

The first phase of emergy analysis is to specify the spatial and temporal boundaries of a certain system and to draw emergy diagram in order to classify the inputs of the system into renewable or non-renewable and local or imported resources. Indeed, emergy diagram shows the inputs and outputs of the system explicitly. This is imperative for the management of the relationships between the main components and the processes of the profitable system and reflects the environmental bases of the ecosystem and its relationship with the larger economy (Odum, 2007). Figure 1 depicts the emergy diagram of the greenhouse cucumber production system in Sistan.

Data collection

The second phase of emergy analysis is to draw the emergy assessment tables. To derive the emergy value of a certain input, its raw information in terms of J, g, or $ is multiplied by its transformity. Total emergy is the sum of the emergies of all independent inputs (Odum et al., 2000). In greenhouse cucumber production system of Sistan, the inputs were considered to include the free renewable resources (sunlight, rain, and wind), the purchased renewable resources (seeds, irrigation water, and labor), and the purchased non-renewable resources (machinery, fossil fuel, chemical fertilizers, pesticides, electricity, and services) and the output was considered to be the newly produced cucumber crop.

Measurement of input emergies

The energy equivalent of the individual inputs of the greenhouse cucumber production system is converted to emergy by Eq. 1 (Brown &Ulgiati, 2004).

$$Emergy\ (seJ)=available\ energy\ (J)\times transformity\ (seJ/J) \quad (1)$$

Solar radiation energy was calculated by Eq.

$$Solar\ radiation\ energy\ (J)=A\ (m^2)\times (Wm^{-2})\times F_{ab}\times 0.62. \quad (2)$$

where A is the land area, *I* is the mean solar radiation in Zabol region during the growing season of different crops, and F_{ab} is the radiation absorption percentage. The radiation absorption percentage of Albedo factor was assumed to be 20% for the greenhouse cucumber production system and the coefficient of sunlight penetration into the greenhouse was assumed to be 60% (Lagerberg, 1999).

Solar transformity to emergy is by definition regarded as 1 seJ J^{-1} (Odum&Odum,1983). The potential chemical energy of rain and irrigation water was calculated by Eq. 3.

Water chemical potential energy (J)=A(m²)×p(mm yr⁻¹) ×d(gm⁻³) ×ΔG(J gr⁻¹) (3)

where A denotes land area, *p* denotes annual rainfall + input water by irrigation (*mm* yr^{-1}), *d* denotes water density (1×10^6 g m^{-3}), and ΔG represents the Gibbs free energy that is 4.94 J gr^{-1} for water (Odum& Odum,1983).

The solar transformity was assumed to be 18,199 seJ J^{-1} for the chemical potential energy of rain water.

The kinetic energy of wind was estimated by Eq. 4.

Wind kinetic energy (J)=A(m²)×r(kg m⁻³) × c (vg)³ (4)

where A represents the land area, *r* depicts air density (1.23 kg m^{-3} air), *c* depicts the Drag constant [1], and *vg* is the geostrophic wind [2].

The solar transformity of wind energy to emergy was supposed to be 1,496 seJ J^{-1}.

The soil energy wastage was estimated by Eq. 5.

Soil energy wastage=A(m²)×Erodsoil (gm⁻² yr⁻¹) ×OM (%)× EOM (kcalgr⁻¹) ×4186JKcal-⁻¹ (5)

where A represents land area, ErodSoil represents soil erosion rate in m^2 yr^{-1}, OM represents soil organic matter percent, and EOM represents soil organic energy content as is 5.4 kcal gr^{-1} (Odum, 2007).

The solar transformity of net surface soil wastage is 1.24 × 105seJ J^{-1} (Odum, 2007).

Labor emergy was considered on the basis of solar transformity of 4.5×10^6 seJ J^{-1} (La Roza et al., 2008).

The coefficient of 15.7×10^6 J kg^{-1} was used to estimate seed content and the solar transformity of 1.11×10^5seJ J^{-1} was applied to calculate seed emergy (Ghaley& Porter. 2013;Ozkan et al., 2004).

The energy content of diesel fuel was calculated by the coefficient of 56.31×10^6seJ L^{-1}. The solar transformity to obtain the emergy of the diesel fuel was assumed to be 1.11×10^5seJ J^{-1} (Odum, 2007; Odum et al., 2000).

The emergy of machinery was considered on the basis of solar transformity of 3×10^{12}seJ kg^{-1} (La Rosa et al., 2008). The coefficient 3.6×10^6 J kWh^{-1} was applied to measure the energy content of the electricity. Also, the emergy of plastic materials was calculated on the basis of solar transformity of 3.72×10^8seJ g^{-1} plastic (Wu et al., 2013).

The solar transformities were assumed to be 2.69×10^5 and 5.43×10^{11}seJ J^{-1} to calculate the emergies of electricity and irrigation water, respectively (Buenfil, 2001; Odum, 2007; Odum et al., 2000).

Also, the solar transformities to estimate the emergies of pesticides and N, P, K, and micro fertilizers were considered to be 1.48×10^{10}seJ J^{-1} (Brown &Arding, 1991), 4.05×10^{10}seJ g^{-1} N (Brandt-Williams, 2002), 3.69×10^{10}seJ g^{-1} P, 3.01×10^9seJ g^{-1} K (Odum, 2007), and 1×10^9seJ g^{-1} micro fertilizer), respectively (Wu et al., 2013).

The energy content of the cucumber crop is 0.8 MJ kg^{-1} (Ozkan et al., 2004).

The solar tranformity to figure out the emergy of dollar was supposed to be 3.12×10^{12}seJ $\$^{-1}$ (Odum, 2007; Odum et al., 2000).

Emergy indices

Below is a brief description of the emergy indices used in system analysis in the present work (La Rosaet al., 2008; Odum et al., 2000; Ulgiati et al., 2004).

• Emergy Yield Ratio (EYR). It is calculated as the emergy purchased inputs divided by emergy output as shown in Eq. 6.

$$EYR= Y/NP+RP \quad (6)$$

[1] *a dimensionless quantity to calculate the Drag force exerted on a moving object*

[2] *Geostrophic wind is a theoretical wind that is derived from the balance between Coriolis wind and pressure gradient force. By definition, its value is considered 1.67 times as high as mean wind speed.*

where Y depicts emergy output, NP represents non-renewable purchased inputs, and RP is the renewable purchased inputs. The higher the index, the higher the return of emergy per the invested emergy.

• *Emergy Investment Ratio* (EIR). This is the economic (purchased) inputs divided by free environmental inputs and is estimated by Eq. 7.

$$EIR=NP+RP/RP+NR \quad (7)$$

where *NP* is the non-renewable purchased inputs, *RP* is the renewable purchased inputs, *NR* is the non-renewable natural inputs, and RR is the renewable natural inputs. Lower EIR reflects lower economic costs; such systems move towards competition in the marketplace. Higher EIR shows more developed economy.

• *Environmental Loading Ratio* (ELR). It indicates the ratio of entire non-renewable environmental and purchased inputs to entire renewable environmental and purchased inputs (Eq. 8).

$$ELR=NP+NR/RR+RP \quad (8)$$

where *NP, NR, RP*, and RR depict the non-renewable purchased inputs, non-renewable natural inputs, renewable purchased inputs, and renewable natural inputs, respectively. This index reflects the rate of pressure on environment and reveals how much the system exploits the environment services. Lower index means less stress and pressure on environment.

• *Emergy self-sufficiency ratio* (ESR). This is calculated as the total emergy of environmental inputs per crop yield emergy as shown in Eq. 9.

$$ESR=RR+NR/Y \quad (9)$$

where *NR* represents the non-renewable natural inputs, *RR* represents the renewable natural inputs, and *Y* represents the emergy of crop yield. ESR indicates the share of environment in a production system. Higher ESR means that system is more dependent on free environmental resources and, from an economic perspective, this system is more capable to enhance the productivity and economic investment.

• *Environmental Sustainability Index* (ESI). This is derived from Eq. 10.

$$ESI=EYR/ELR \quad (10)$$

where *EYR* is the emergy yield ratio and *ELR* is the environmental loading ratio. This index indicates if we can find a process that exert less pressure on environment and, at the same time, has a good yield. ESI considers the adaptability of both economic sector and environment (Brown & Ulgiati, 2004) state that not only does the feedback reduction increase the index, but higher ratio of renewable inputs to feedbacks also enhances this ratio. Higher ESI reflects higher sustainability of the agronomic system.

RESULTS

Table 2 displays the analysis of data pertaining to greenhouse cucumber production inputs and outputs in Sistan Region.

As is evident in Table 2, the highestemergy amount of 7.9×10^{17}seJ ha^{-1} was related to diesel fuel consumption and the second highest one ($1.92 * 10^{17}$seJ ha^{-1}) to labor.

In an assessment of greenhouse tomato emergy in Swiss (Lagerberg,1999) found that the highest emergy consumption was associated with fossil fuel (7.36×10^{17}seJ ha^{-1}) followed by labor (4.54×10^{17}seJ ha^{-1} (Wu et al., 2013) analyzed greenhouse vegetables system in Northwestern China and estimated emergy consumption rate of labor and electricity at 8.65×10^{16} and 3.03×10^{16}seJ ha^{-1}, respectively. Also, in the assessment of cucumber emergy in California by Brant Williams, the highest consumed emergy (4.11×10^{15}seJ ha^{-1}) was found to be related to the service and the labor and fossil fuel exhibited the next highest consumed emergies of 2.85×10^{15} and 2.43×10^{15}seJ ha^{-1}, respectively.

High emergy of diesel fuel is due to the inefficient energy and heat generators and their low transformity as well as improper buildings and structures of the local greenhouses. Also, high emergy of labor can be related to the manual planting, cultivating and harvesting by workers.

The different resources of emergy involved in greenhouse cucumber system in Sistan are categorized in Table 3. Accordingly, the natural resources (R + N) had less than 0.5% share in total consumed emergy, but the share of the purchased resources (P) was 99.95%. Total renewable resources (R + RP) and non-renewable resources accounted for 18.7 and 81.3% of total emergy, respectively (Figure 2). Total emergy yield of greenhouse cucumber production in Sistan was estimated at 1.094 × 1018seJ ha^{-1} and the greenhouse cucumber transformity at 4.94×10^{6}seJ J^{-1}.

Figure 2. Renewable and nonrenewable resources of greenhouse cucumber system

Emergy indices

Emergy indices for greenhouse cucumber production are presented in Table 4. It was found that renewability percent (%R) was 18.75 for cucumber. It reflects the share of renewable resources in total production resources so that the lower it is, the lower the renewability potential of the system and the lower its sustainability.

Emergy yield ratio (EYR)

It was estimated at 1 for the greenhouse cucumber of Sistan. Higher EYR is more favorable

Table 2
The Assessment of the Emergy of Greenhouse Cucumber System in Sistan Region

Note	Item	Unit	Data	Transformity	Emergy	%
	Renewable natural resources					
1	sunlight	J	2.04×10^{13}	1	2.04×10^{13}	0.001
2	wind	J	5.5×10^{6}	1496	8.2×10^{9}	0.000
3	water	m^3	925	5.43×10^{11}	5.02×10^{14}	0.045
	total	J			5.23×10^{14}	0.047
	Nonrenewable natural resources		.	1.24×10^{5}	0	0.00
4	Topsoil					
	Renewable purchased resources					
5	Labor	J	4.26×10^{10}	4.5×10^{6}	1.92×10^{17}	17.55
6	Seed	$	3.45×10^{3}	3.12×10^{12}	1.07×10^{16}	0.97
7	Manure	J	1.82×10^{4}	2.7×10^{4}	4.91×10^{8}	0.00
	Total				2.04×10^{17}	18.7
	Nonrenewable purchased resources					
8	Fuel	J	7.18×10^{12}	1.11×10^{5}	7.9×10^{17}	72.21
9	Machinery	Kg	4.75	3.00×10^{12}	1.42×10^{13}	0.001
10	Electricity	J	5.67×10^{10}	2.69×10^{5}	1.52×10^{16}	1.39
11	Plastic	g	4.00×10^{6}	3.72×10^{8}	1.49×10^{15}	0.13
12	Nitrogen	g	4.50×10^{5}	4.05×10^{10}	1.8×10^{16}	1.64
13	Phosphate	g	3.5×10^{5}	3.69×10^{10}	1.29×10^{16}	1.18
14	Potash	g	4.50×10^{5}	3.01×10^{10}	1.35×10^{15}	0.12
15	Micronutrient	g	4.80×10^{5}	1.00×10^{9}	4.80×10^{14}	0.04
16	Pesticide	g	1.00×10^{4}	1.48×10^{10}	1.48×10^{14}	0.02
17	Services	$	1.2×10^{4}	3.12×10^{12}	3.74×10^{16}	3.41
	total				8.89×10^{17}	81.25
	Emergy yield				1.094×10^{18}	100
	Output					
18	Cucumber	Kg	275000			
19	yield	J	2.2×10^{11}	4.94×10^{6}	1.094×10^{18}	
20	energy	Solar J/g	3.97×10^{9}			
	Specific emergy					

Table 3
The General Categorization of Different Emergy Resources of Cucumber System in Sistan

Note	Item	Unit/ha	Data
Natural resources			
1	Renewable natural resources	5.23×10^{14}	0.047
2	Nonrenewable natural resources	0	0.00
3	Total		0.047
Purchased resources			
4	Renewable purchased resources	2.046×10^{17}	18.7
5	Nonrenewable purchased resources	8.89×10^{17}	81.35
6	total		
7	Total emergy	1.093×10^{18}	99.95
8	Cucumber	1.094×10^{18}	100
	transformiyy	4.94×10^{6}	

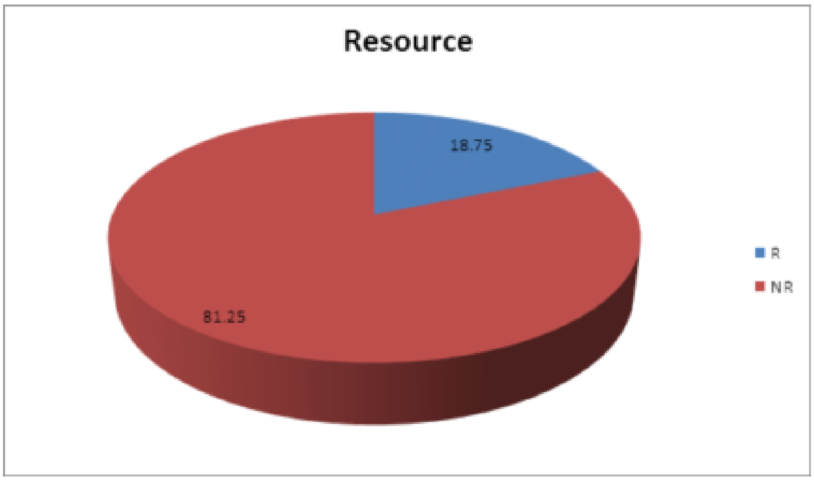

Figure 2. Renewable and nonrenewable resources of greenhouse cucumber system

and vice versa because it displays emergy yield ratio as per invested emergy. In the assessment of greenhouse tomato emergy in Swiss (Lagerberg, 1999) estimated EYR at 1 as we did. La Rosa et al (2008) explored orange emergy in Italy and calculated this index as 1.5. It was reported as to be 1.07 by Feng et al. (2013) in a study on grapes in Southwestern China.

• *Emergy investment ratio (EIR)*

It shows the economic investment consumed in the system. Thus, higher EIR reflects higher share of the purchased resources. We calculated EIR as to be 2089 for greenhouse cucumber production, implying the exclusive reliance of the system to the purchased resources vs. free environmental resources. Lower EIR is more desirable. Feng et al. (2013) reported EIR as to be 14.08 for grapes in Southwestern China.

• *Environmental loading ratio (ELR)*

This ratio shows the pressure and stress incurred by a planting system on environment. In general, ELR of about two or less implies relatively low environmental impacts that of 3-10 implies moderate environmental impacts, and that of greater than 10 shows strong environmental impacts (Cavalett& Ortega, 2009). We found it to be 4.34 for the greenhouse cucumber in Sistan. Lagerberg (1999) estimated it at 318 for greenhouse tomato production in Swiss. Wu et al. (2013) reported it as to be 3.92 for greenhouse vegetables system in Northwestern China.

• *Emergy self-sufficiency ratio (ESR)*

This ratio reflects the system's reliance upon its internal resources. The higher the ESR is, the better it is. We found that it was 0.0004 for greenhouse cucumber production (Lagerberg,

Table 4
EmergyIndices for Cucumber Planting System in Sistan

Note	Item	Cucumber
1	Renewability(R%)	18.75
2	Emergy yield ratio(EYR)	1.00
3	Emergy investment ratio (EIR)	2089
4	Environmental loading ratio (ELR)	4.34
5	Emergy self-sufficiency ratio (ESR)	0.0004
6	Environmental sustainability index (ESI)	0.23

Table 5
TheComparison of Emergy Indices in Some Agricultural Systems around the World with the Present Study

Product	ESI	ELR	EYR	F	N	R	Tr
Oats (florida)	0.68	2.64	1.79	3.1×10^{15}	9.5×10^{14}	1.56×10^{15}	2.09×10^{5}
Potatoes (florida)	0.16	7.52	1.24	1.03×10^{16}	9.5×10^{14}	1.49×10^{15}	1.49×10^{5}
Barley (washington)	0.78	2.94	2.28	8.38×10^{14}	5.9×10^{14}	4.87×10^{14}	9.24×10^{4}
Vegetable (washington)	0.01	71.27	1.01	4.12×10^{15}	-	5.78×10^{13}	8.74×10^{5}
Orange (italy)	0.03	43	1.5	1.5×10^{16}	7.7×10^{15}	5.2×10^{14}	1.20×10^{9}
Grape (china)	0.39	2.78	1.07	1.86×10^{15}	1.54×10^{13}	1.54×10^{14}	6.0×10^{5}
Corn (china)	0.45	2.67	1.2	2.3×10^{15}	1.95×10^{14}	2.66×10^{14}	9.74×10^{4}
Rice (china)	1.83	0.62	1.15	2.07×10^{16}	-	3.00×10^{15}	1.39×10^{5}
Wheat (china)	0.11	10.59	1.19	1.68×10^{16}	1.82×10^{16}	1.72×10^{15}	1.63×10^{5}
Tomato (swhdish)	0.003	318	1.00	1.37×10^{18}	-	2.96×10^{14}	7.39×10^{12}
Vegetable (china)	20.59	3.92	1.01	3.40×10^{17}	-	4.86×10^{15}	5.95×10^{5}
Greenhouse cucumber (sistan)	0.23	4.34	1	1.09×10^{18}	-	5.23×10^{14}	4.94×10^{6}

1999) estimated it at 0.0002 for greenhouse tomato system in Swiss and Wu et al. (2013) reported that it was 0.014 for greenhouse vegetables system in Northwestern China.

• *Environmental sustainability index (ESI)*

ESI is a measure of a planting system's sustainability. As the share of renewable resources is increased versus non-renewable resources, this index is enhanced and improved. It was calculated to be 0.23 for greenhouse cucumber system in Sistan Region. It was reported to be 0.003 for greenhouse tomato in Swiss by Lagerberg (1999) and 20.95 for greenhouse vegetables system in Northwestern China by Wu et al. (2013).

Table 4 briefly compares our findings with similar studies in other parts of the world (Haden, 2002).

DISCUSSION AND CONCLUSION

The present paper analyzed the divergent resources of energy and major environmental sustainability and loading indices for greenhouse cucumber production in Sistan using emergy assessment technique. It was revealed that total emergy was 1.094×10^{18}seJ for greenhouse cucumber production. Among inputs involved in this activity, diesel fuel and labor accounted for 72.21 and 17.55% of energy consumption, respectively. If energy consumption is intended to be optimized, it is imperative to prioritize these two variables, especially diesel fuel because it naturally has a high consumption rate in greenhouse systems, so the reduction of its use can deeply influence energy use, particularly the use of fossil fuels. It would also result in the saving of production costs. As well, the analysis of emergy indices revealed that renewability index (R%) was 6418.75, EYR was 1.00, EIR was 2089, ELR was 4.34, ESR was 0.0004, and ESI was 0.23 for greenhouse cucumber system in Sistan. The comparison of our results with similar studies, as summarized in Table 5, shows that the emergy indices of greenhouse cucumber system in Sistan are moderate as compared to similar systems around the world. Environmental loading ratio is of crucial importance. The lower it is, the lower the pressure that is exerted on the environment. Its amount for greenhouse cucumber production in Sistan (4.34) was moderate as compared to the mean global value estimated by Sweeney et al. (2007). The value derived for greenhouse cucumber system in Sistan looks reasonable given the nature of greenhouse systems that mostly rely on the purchased inputs and have higher environmental pressure than farm and horticulture systems. The environmental sustainability index for greenhouse cucumber in Sistan is lower than the global average, implying its relatively weak sustainability. This is associated with the high dependence on non-renewable inputs and the small role of renewable resources in greenhouse cucumber production in Sistan. Since greenhouse production systems have played an unavoidable role in water saving and higher production per unit area, despite their high environmental pressure and low sustainability, they are developing rapidly especially in arid regions with water constraints. Thus, extensive research is required to reduce their environmental pressure, improve their sustainability, and reduce their dependence on the purchased inputs particularly fossil fuels and labor by changing greenhouse structures, enhancing energy use efficiency inside the greenhouse, and mechanizing the planting, cultivating and harvesting processes.

Given the results, the following recommendations can be made for the better management of energy resources:

1. It is recommended to use emergy assessment technique for precise analysis of energy resources of all farming systems.

2. Since diesel fuel and labor are the main contributors to energy use in greenhouse cucumber production system in Sistan region, it is recommended to prioritize their optimization by changing greenhouse structures, enhancing energy use efficiency inside the greenhouse, and mechanizing the planting, cultivating and harvesting processes.

3. Water deficiency is a big limitation in agriculture in Iran. Fortunately, consumption of water energy is very low for greenhouse cucumberproduciton. Therefore, greenhouse cucumber growing and development could be a solution for drought, if consumption of other energy inputs like fossils fuels is optimized.

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