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Ranking wheat-producing provinces of Iran based on eco-efficiency

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Abstract

This research ranked wheat-producing provinces of Iran based on cross-efficiency and eco-efficiency. Eco-efficiency measured by cross-efficiency in which greenhouse gas (GHG) emissions were regarded as an undesirable output. Data required for the research on the amount of input consumption, yield, and revenue were derived from the databases of the Ministry of Agriculture Jahad for 2018 and were analyzed using the MATLAB and MS-Excel software packages. The ranking of irrigated wheat-producing provinces based on cross-efficiency showed that Lorestan was in the first rank. Based on eco-efficiency the ranks of 19 provinces were changed by one to five levels. Ardabil, Isfahan, Fars, and Mazandaran downgraded the most. Cross-efficiency based on revenue revealed that Kohgiluyeh and Boyer-Ahmad, attained the first ranks. Based on the results of cross-efficiency of rainfed wheat-producing regions, South Khorasan, Kohgiluyeh and Boyer-Ahmad, and Zanjan consume inputs more optimally. In general, it was revealed that the provinces with higher cultivated areas and production did not have higher efficiency. It appears that in comparison with other provinces, production inputs are not used in these regions optimally. Given the status of these provinces in cultivated areas and production, any plan to increase production requires to seriously consider the optimal use of resources as well as the environmental effects.

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Introduction

Wheat is one of the most important crops for humans' food security. This crop constitutes an important part of the food regime throughout the world and is the most important source of calories for humans (Sadok et al., 2019). Wheat accounts for about 20 percent of total calorie and food protein intake in the world and is one of the most important grains with an annual acreage of over 220 million ha in a wide range of climatic conditions and geographical regions (Shiferaw et al., 2013). Among Middle East countries, wheat yield in Iran (about 2 t/ha) is lower than that in countries like Kuwait, Saudi Arabia, Turkey, Cyprus, and Iraq, reflecting the need for provisions to increase its yield and production (FAO, 2020). Although self-sufficiency policies in Iran have contributed to enhancing its production rate at times, statistics show that this increase to the self-sufficiency level has not been sustainable so that wheat import has sometimes increased sharply (Figure1).

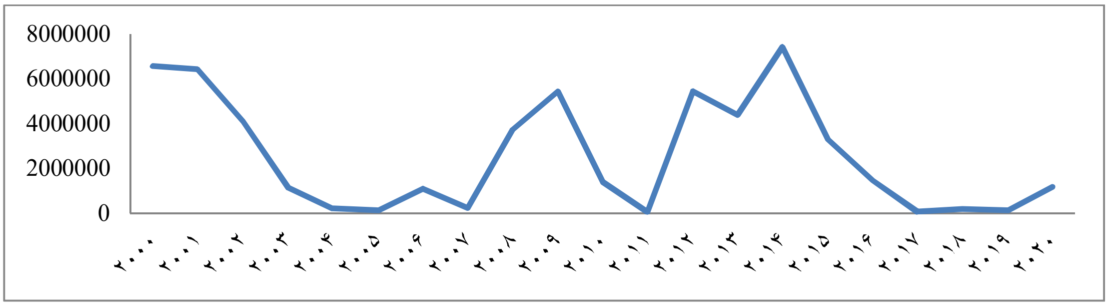

Figure 1. Import quantity of wheat by Iran (FAO,2020)

The wheat production system will be influenced by heat stresses and water scarcity caused by climate change, especially in South and West Asian and North African countries (Shiferaw et al., 2013). Global warming due to climate change is estimated to reduce irrigated wheat yield by 5.3-7.4 percent in developing countries and by up to 0.1 percent in developed countries (Nelson et al., 2010).

The urgent need to achieve food security in developing countries has led to the adoption of policies and tools that may be harmful to the environment (Peng et al., 2015; Verburg et al., 2013). Therefore, given the implications of climate change and the effects of the environment on food production and agriculture, it is necessary to consider food security in an environmental context (Fuss et al., 2015; Krishnamurthy et al., 2014). The negative effect of food production on environmental quality should be alleviated and future demand for food should be satisfied by increasing the productivity of production factors as much as possible at no expense on expanding agricultural and grazing lands (Adom & Adams, 2020). In other words, the growing global demand for food should be met by increasing production efficiency due to resource limitations (Majiwa et al., 2018). Therefore, a requirement for achieving sustainable agriculture and reducing resource depletion is to use production resources more efficiently (Masuda, 2016; Shanmugam & Venkataramani, 2006). In this regard, plans and policies should be oriented towards enhancing efficiency and alleviating environmental impacts. Eco-efficiency was proposed in the 1990s as a tool to link economic activities to sustainable development (Schaltegger and Synnestvedt, 2002).

Eco-efficiency plays a key role in expressing the efficiency of economic activities with respect to the capacity of natural resources (Qian et al., 2018). As a practical tool for the business sector, this concept focuses on resource use practices that allow achieving economic and environmental advancement by more efficient use of resources and less pollution (Freudenreich and Schaltegger, 2019). Eco-efficiency has been designed to increase the efficiency of economic activities in terms of both production resource use and its corresponding environmental impacts (ESCAP, 2009).

Studies have been conducted on different crops to investigate the efficiency and the reduction of environmental impacts (Al-Mezeini et al., 2020; Bolandnazar et al., 2014; Ebrahimi & Salehi, 2015; Esfahani et al., 2017; Shahnavazi, 2020). These studies have mostly used models of efficiency measurement in which the efficiency of one or some certain crops is determined in a certain region and then the potential of reducing environmental effects by improving efficiency is estimated. These studies have not considered environmental impacts as the undesirable output along with yield or net profit as the desirable output. So, it seems imperative to conduct a study to rank different regions of Iran in terms of the optimal use of resources by considering adverse environmental impacts as an undesirable output along with the desirable output. As such, the regions that are apt to production can be recognized and the planning and policymaking process of production can be oriented towards efficient use of resources and the alleviation of environmental effects. Therefore, given the orientation of policies towards increasing staple crop production, especially wheat, this research aims to determine the status of provinces in production considering greenhouse gas (GHG) missions as an undesirable output. The results can provide planners and policymakers of the agricultural sector with valuable information.

Materials and Methods

Study site and data collection

Iran is located in the southwest of Asia, and about 12 million ha of its area has been dedicated to crop production – 52 percent for irrigated farming and 48 percent for rainfed farming. In recent years, emphasis has always been placed on increasing wheat production up to a self-sufficiency level in order to ensure sustainable food security. Wheat production rate is the second (10 million tons) among irrigated crops after forage corn and the first (5.5 million tons) among rainfed crops whereas wheat production accounts for about 32 percent of the total irrigated farming lands and 70 percent of the total rainfed farming lands. The main irrigated wheat-producing provinces are Khuzestan, Fars, Golestan, Khorasan Razavi, Kermanshah, and Hamedan, which account for 17, 13, 7, 6.5, 5.5, and 4.5 percent of the total irrigated wheat production, respectively. Also, rainfed wheat is mainly produced in the provinces of Kurdistan, Golestan, East Azerbaijan, Kermanshah, and West Azerbaijan accounting for 15.8, 12.6, 9, 7, and 6.8 percent of the total rainfed wheat production, respectively (Ministry of Agriculture-Jahad of Iran, 2020) .

The research data requirement on the amount of crop production, the amount of chemical inputs consumed including nitrogen, phosphate, and potash fertilizers, chemical pesticides, manure, and water, gross sales revenue, and production costs for different crop-producing provinces and regions were derived from the statistic books of the Ministry of Agriculture Jahad and analyzed using the MATLAB and MS-Excel software packages.

Cross-efficiency

Data envelopment analysis (DEA) is extensively used to assess the efficiency of decision-making units (DMUs). Due to the flexibility of this method in selecting input and output weights and the nature of self-assessment, many DMUs are shown to be efficient, however the lack of discrimination of inefficient DMUs is a big problem of DEA models (Guo & Wu, 2013; Sadeghi Gavgani & Zohrehbandian, 2014). So, researchers have tried to improve this model to increase its discriminating power and the full ranking of DMUs. To better discriminate efficient DMUs by DEA and assign more realistic weights, cross-efficiency was proposed. Saxton et al. (1986) proposed a set of weights of other DMUs to determine the efficiency score of a certain DMU instead of weight-assignment based on the DMU’s own information. At first, the efficiency of each DMU is calculated with a constant return to scale by DEA and then, the weights obtained in the first step are applied to all DMUs to estimate cross-efficiency (Jahanshahloo et al., 2011).

The DEA model with a constant return to scale is as follows (Zhu et al., 2020).

$$E_{dd} = Max \frac{\sum_{r=1}^{s} u_{rd} y_{rd}}{\sum_{i=1}^{m} v_{id} x_{id}}$$

$$st: \qquad (1)$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1$$

$$u_r \geq 0, v_r \geq 0$$

in which y_{rd} and x_{id} are the amount of output and input and u_{rd} and v_{id} are the weight of the outputs and inputs of the DMU *d*, respectively. Also, y_{rj} and x_{ij} represent the outputs and inputs of the

DMU j. Eq. (1) can be converted to model (2) as follows (Li et al., 2020):

$$E_{dd} = max \sum_{r=1}^{s} u_{rd} \cdot y_{rd}$$
$$\sum_{i=1}^{m} v_{id}\, x_{id} = 1 \quad (2)$$
$$\sum_{r=1}^{s} u_{rd} \cdot y_{rj} - \sum_{i=1}^{m} v_{id} \cdot x_{ij} \le 0$$

The cross-efficiency of the DMUs j and d is expressed as Eq. (3) provided that $j \neq d$. In Eq. (3), u_{rd} and v_{id} are optimal weights that are obtained from Eq. (2)(Liu et al., 2019).

$$v_{id}, u_{rd} \ge 0$$
$$E_{dj} = \frac{\sum_{r=1}^{s} u_{rd} y_{rj}}{\sum_{i=1}^{m} v_{id}\, x_{ij}} \quad (3)$$

Cross-efficiency in the presence of undesirable outputs

When assessing and ranking production units, it should be noted that the use of inputs for crop production in the real world can create undesirable outputs. For example, the application of exogenous inputs in crop production will emit environmental pollutants, which should be considered in the assessment and ranking of DMUs. As such, the output of a certain DMU will have undesirable outputs (y_{pj}) in addition to desirable outputs (y_{rj}). To consider undesirable outputs in the DEA model, they are typically included in the model as an input because it is argued that DMUs aim to minimize undesirable outputs in addition to inputs (Guo & Wu, 2013; Yang & Pollitt, 2010). Another approach is measuring efficiency scores in the presence of undesirable outputs. Eq. (4) has been proposed to measure a DMU's efficiency in the presence of undesirable outputs (Liu et al., 2015):

$$E_{dd} = \max \sum_{r=1}^{s} u_{rd} \cdot y_{rd} + \sum_{d=1}^{k} \varphi_{pd} \cdot \hat{y}_{pd}$$
$$st.$$
$$\sum_{r=1}^{s} u_{rd} \cdot y_{rj} + \sum_{d=1}^{k} \varphi_{pj} \cdot \hat{y}_{pj} - \sum_{i=1}^{m} v_{id} \cdot x_{ij} \le 0 \quad (4)$$
$$\sum_{i=1}^{m} v_{id}\, x_{id} = 1$$
$$\sum_{r=1}^{s} u_{rd} \cdot y_{rd} \ge \alpha . \varepsilon^*$$
$$\sum_{d=1}^{k} \varphi_{pd} \cdot \hat{y}_{pd} \ge \beta . \varepsilon^*$$
$$v_{id}, u_{rd}, \varphi_{pj} \ge 0$$

Eq. (5) is used to quantify $\hat{y}_{pd}$.

$$\hat{y}_{pd} = w_p - y_{pd} \quad (5)$$

in which w_p is an n-dimensional vector that can convert undesirable negative outputs to positive outputs. In addition, α and β are parameters that represent the smallest percentage of ε^*. It is assumed here that α = β = 0.2. Also, the value of ε^* is estimated by model (6) as follows (Aghayi & Maleki, 2016).

$$\varepsilon^* = \max \varepsilon_d$$
$$st. \sum_{i=1}^{m} v_{id} \cdot x_{ij} = 1$$
$$\sum_{i=1}^{m} v_{id} \cdot x_{ij} - \sum_{r=1}^{s} u_{rd} \cdot y_{rj} - \sum_{d=1}^{k} \varphi_{pj} \cdot \hat{y}_{pj} \ge 0 \quad (6)$$
$$\sum_{r=1}^{s} u_{rd} \cdot y_{rd} \ge \alpha . \varepsilon_d$$
$$\sum_{d=1}^{k} \varphi_{pd} \cdot \hat{y}_{pd} \ge \beta . \varepsilon_d$$
$$v_{id}, u_{rd}, \varphi_{pj} \ge 0$$

Accordingly, the cross-efficiency of the DMU j corresponding to the DMU d is obtained by Eq. (7):

$$E_{dj} = \frac{\sum_{r=1}^{s} u_{rd}^* y_{rj} + \varphi_{pd}^* \cdot \hat{y}_{pj}}{\sum_{i=1}^{m} v_{id}^* x_{ij}} \quad (7)$$

After the cross-efficiency matrix is constructed, the efficiency of the DMU j can be calculated by Eq. (8) as follows (Li et al., 2020):

$$E_j = \frac{1}{n} \sum_{d=1}^{n} E_{dj} \quad (8)$$

Greenhouse gas (GHG) emissions

The research considered GHG that is emitted during crop production as an undesirable output. N_2O, CH_4, and CO_2 are the most important GHGs, and the agricultural sector accounts for an important part of their emission due to the consumption of chemical inputs. These pollutants do not influence global heating capacity equally so that the effect of N_2O and CH_4 is greater on this parameter than the effect of CO_2 (Yousefi et al., 2014). The rate of GHG emission by each agricultural input is calculated by multiplying the amount of their consumption by the equivalent emission coefficient. These factors for different inputs are presented in Table 1.

Table 1. GHG emission coefficients of different inputs (gr)

Input	Unit	CH_4	N_2O	CO_2	Reference
Nitrogen(N)	kg	3.70	0.03	3100	(Snyder et al., 2009)
Phosphorus (P2O5)	kg	1.80	0.02	1000	(Snyder et al., 2009)
Potassium (K2O)	kg	1.00	0.01	700	(Snyder et al., 2009)
Manure	kg	*	*	126	(Nikkhah et al., 2015)
Insecticide	l	*	*	5300	(Lal, 2004)
Herbicide	l	*	*	6300	(Lal, 2004)
Fungicide	l	*	*	3900	(Lal, 2004)
Co2 equivalence factor		21	310	1	(Yousefi et al., 2014)

Results and Discussion

The mean rate of GHG emission by irrigated wheat production was estimated at 847 kg CO_2.eq/ha. Nitrogen and phosphate fertilizers contributed the greatest fractions, and fungicides and insecticides contributed the smallest fractions in this GHG emission (Table 2). Previous studies have reported the GHG emission of wheat lands in Iran to be 1137 and 637 kg CO_2-eq/ha in the provinces of Golestan and Razavi Khorasan, respectively (Motamedolshariati et al., 2017; Soltani et al., 2013).

Table 2. GHG emission of one hectare of irrigated wheat (in kg CO_2.eq)

	K fertilizer	N fertilizer	P fertilizer	Fungicide	Herbicide	Insecticide	Manure	Total
Average	19.95	647.93	103.64	0.47	3.29	5.36	94.23	874.87
Max	55.89	954.42	146.51	4.15	7.35	8.64	716.95	1806.84
Min	0.00	256.68	53.59	0.00	0.00	0.61	0.00	319.72
Sd	15.68	173.02	21.90	0.99	2.13	2.23	146.85	278.34

It is estimated that 272 kg CO_2.eq/ha of GHG is emitted by rainfed wheat lands mainly accounted for by nitrogen fertilizers followed by phosphate fertilizers and manure (Table 3). Previous studies in Iran have calculated the GHG emission of rainfed wheat lands at 404 kg CO_2.eq/ha in Kerman Province and 280.57 kg CO_2.eq/ha in Kohgiluyeh and Boyer-Ahmad Province (Khoshroo, 2014; Moradi & Pourghasemian, 2017).

Table 3.GHG emission of one hectare of rainfed wheat (kg CO_2.eq)

	K fertilizer	N fertilizer	P fertilizer	Fungicide	Herbicide	Insecticide	Manure	Total
Average	37.13	212.02	1.83	17.55	1.88	1.06	0.53	272.00
Max	104.40	474.84	35.79	126.00	7.02	5.10	3.77	628.18
Min	0.00	5.04	0.00	0.00	0.00	0.00	0.00	5.04
Sd	24.79	125.06	6.93	31.85	2.40	1.43	1.09	158.47

After the rate of GHG emissions was calculated, the eco-efficiency was measured to rank different regions in crop production.

The ranking of the provinces based on cross-efficiency shows that the provinces of Lorestan, Kohgiluyeh and Boyer-Ahmad, and Bushehr are in the first to third ranks, respectively (Table 4). Ranking based on eco-efficiency changed the rank of 19 provinces by one to five steps versus ranking based on cross-efficiency. As such, the provinces of Mazandaran, Eastern Azerbaijan, Khuzestan, Fars, Isfahan, Chahar Mahal Bakhtiari, Tehran, South of Kerman, and Ardabil went down in the ranking. This downgrading was greater for the provinces of Ardabil, Isfahan, Fars, and Mazandaran than for the other provinces, calling for attention to environmental issues and other environmentally more harmful inputs. The upgrading of the provinces of Southern Khorasan, Qazvin, Qom, Alborz, Northern Khorasan, Hormozgan, Zanjan, Hamedan, and Sistan and Baluchestan may imply attention to environmental issues and the reduction of GHG emissions during irrigated wheat production.

Table 4. The cross-efficiency, eco-efficiency, and rank of irrigated wheat-producing provinces (yield as the desirable output)

Province	Cross-efficiency	Rank	Eco-efficiency	Rank
Markazi	0.3089	17	0.2987	17
Mazandaran	0.3223	15	0.2898	18
East Azerbaijan	0.3619	13	0.3503	14
West Azerbaijan	0.4352	7	0.4003	7
Kermanshah	0.4089	9	0.3961	8
Khuzestan	0.4937	5	0.4460	6
Fars	0.2866	18	0.2644	21
Kerman	0.5302	4	0.4776	4
Isfahan	0.2545	22	0.2396	26
Sistan and Baluchestan	0.3871	12	0.3944	9
Kurdistan	0.3189	16	0.3043	16
Hamadan	0.2758	20	0.2756	19
Chaharmahal and Bakhtiari	0.2308	26	0.2334	27
Lorestan	0.7184	1	0.7238	1
Ilam	0.3960	11	0.3821	11
Kohgiluyeh and Boyer-Ahmad	0.6450	2	0.6932	2
Bushehr	0.5337	3	0.5453	3
Zanjan	0.4373	6	0.4530	5
Semnan	0.1989	30	0.2099	30
Yazd	0.3995	10	0.3876	10
Hormozgan	0.2731	21	0.2688	20
Tehran	0.2508	23	0.2473	24
Golestan	0.2436	25	0.2464	25
Qazvin	0.2839	19	0.3267	15
South of Kerman	0.2184	28	0.2192	29
Ardabil	0.4100	8	0.3575	13
Qom	0.3509	14	0.3751	12
South Khorasan	0.2306	27	0.2594	22
Razavi Khorasan	0.1615	31	0.1699	31
North Khorasan	0.2506	24	0.2583	23
Alborz	0.1994	29	0.2244	28

Given the role of cost management and production profitability in motivating production escalation and continuation, efficiency was also calculated by considering revenue as a desirable output in order to include cost management along with input use management and GHG emissions (Table 5).

According to cross-efficiency based on revenue, the provinces of Kohgiluyeh and Boyer-Ahmad, Kerman, and Zanjan were ranked first to third, respectively. Also, the southern part of Kerman, Khorasan Razavi Province, and Alborz Province were placed at the bottom of the table (Table 5). The eco-efficiency based on revenue shows that Kohgiluyeh and Boyer-Ahmad Province is at the top followed by the provinces of Lorestan, Zanjan, Kerman, and Yazd. The provinces of Southern Khorasan, Khorasan Razavi, Alborz, and Golestan are seen at the last ranks. When GHG emissions were included, the provinces of Northern Khorasan, Mazandaran, and Eastern Azerbaijan were downgraded by 4, 3, and 3 ranks, respectively, reflecting less attention to environmental issues in these provinces. On the other hand, the provinces of Qazvin, Ilam, and Fars were upgraded by 4, 3, and 3 ranks, respectively. So, these latter provinces pay more attention to environmental issues, and the profitability of wheat production in them has less environmental impacts. The provinces of Alborz, Qazvin, and Zanjan were upgraded when eco-efficiency was calculated based on yield whereas the estimation of eco-efficiency based on net profit did not improve their ranking. It can, therefore, be said that production increase and gross profit increase are not proportional in these provinces and it is necessary to consider profitability and cost management along with production increase.

Table 5.The cross-efficiency, eco-efficiency, and ranking of irrigated wheat production (revenue as a desirable output)

Province	Cross-efficiency	Rank	Eco-efficiency	Rank
Markazi	0.2568	17	0.2426	18
Mazandaran	0.1861	24	0.1914	21
East Azerbaijan	0.2731	16	0.2843	13
West Azerbaijan	0.3771	10	0.3779	8
Kermanshah	0.3333	12	0.3161	11
Khuzestan	0.2791	14	0.2711	14
Fars	0.1914	23	0.1635	26
Kerman	0.5958	2	0.5330	4
Isfahan	0.1702	25	0.1374	27
Sistan and Baluchestan	0.4036	7	0.4310	6
Kurdistan	0.2741	15	0.2456	16
Hamadan	0.2873	13	0.2581	15
Chaharmahal and Bakhtiari	0.2138	21	0.2040	19
Lorestan	0.5331	4	0.6093	2
Ilam	0.3926	9	0.3123	12
Kohgiluyeh and Boyer-Ahmad	0.6268	1	0.6636	1
Bushehr	0.3422	11	0.3560	10
Zanjan	0.5812	3	0.5332	3
Semnan	0.2185	20	0.1920	20
Yazd	0.5069	5	0.4840	5
Hormozgan	0.1460	27	0.1712	25
Tehran	0.2120	22	0.1782	24
Golestan	0.1434	28	0.1369	28
Qazvin	0.2363	19	0.1799	23
South of Kerman	0.0093	31	0.0094	31
Ardabil	0.4360	6	0.3903	7
Qom	0.4032	8	0.3693	9
South Khorasan	0.2560	18	0.2436	17
Razavi Khorasan	0.0435	30	0.0431	30
North Khorasan	0.1684	26	0.1864	22
Alborz	0.1015	29	0.0936	29

The results of the cross-efficiency based on yeild of rainfed wheat production reveal that the provinces of South Khorasan, Kohgiluyeh and Boyer-Ahmad, and Zanjan consume inputs for rainfed wheat production more optimally. Also, the provinces of Bushehr, Northern Khorasan, Semnan, and Markazi gained the worst efficiency scores. The inclusion of GHG emissions as an undesirable output of rainfed wheat production did not change the ranking of the provinces significantly. Only the three provinces, Northern Khorasan, Ilam, and Khuzestan, were upgraded by one rank and Chahar Mahal Bakhtiari, Bushehr, and Razavi Khorasan were downgraded by one rank.

Data on production costs and gross profits showed that the revenue of rainfed wheat production in four provinces of Fars, Qazvin, Khorasan Razavi, and Bushehr could not cover its production costs so that gross profit was negative in these provinces. Hence, these provinces were excluded from the calculation of cross-efficiency based on revenue.

Table 6.The cross-efficiency, eco-efficiency and ranking of rainfed wheat production (yield as the desirable output)

Province	Cross-efficiency	Rank	Eco-efficiency	Rank
Markazi	0.1307	24	0.1281	24
Gilan	0.4826	4	0.4839	4
Mazandaran	0.1570	20	0.1547	20
East Azerbaijan	0.2747	15	0.2729	15
West Azerbaijan	0.2768	14	0.2752	14
Kermanshah	0.2642	16	0.2607	16
Khuzestan	0.3282	9	0.3173	10
Fars	0.2231	17	0.2221	17
Kerman	0.2906	13	0.2829	13
Isfahan	0.3166	11	0.3151	11
Kurdistan	0.1642	19	0.1613	19
Hamadan	0.1888	18	0.1866	18
Chaharmahal and Bakhtiari	0.3184	10	0.3174	9
Lorestan	0.3414	8	0.3239	8
Ilam	0.1414	22	0.1403	23
Kohgiluyeh and Boyer-Ahmad	0.8011	2	0.7576	2
Bushehr	0.0426	27	0.0846	26
Zanjan	0.5239	3	0.5119	3
Semnan	0.1206	25	0.1186	25
Tehran	0.4555	5	0.4535	5
Golestan	0.1555	21	0.1545	21
Qazvin	0.3123	12	0.3063	12
Ardabil	0.3557	7	0.3427	7
Qom	0.4416	6	0.4442	6
South Khorasan	0.8333	1	0.8484	1
Razavi Khorasan	0.1403	23	0.1519	22
North Khorasan	0.0776	26	0.0767	27
Markazi	0.1307	24	0.1281	24
Gilan	0.4826	4	0.4839	4
Mazandaran	0.1570	20	0.1547	20
East Azerbaijan	0.2747	15	0.2729	15

Based on revenue, the provinces of Kohgiluyeh and Boyer-Ahmad, Southern Khorasan, Kerman, and Tehran were ranked first to fourth, respectively. Also, when GHG emissions were included, Hamedan was upgraded by two ranks and East Azerbaijan was downgraded by two ranks (Table 7).

According to the results, among the main irrigated wheat-producing provinces, none had an optimal efficiency. Among the main wheat producers, Khuzestan, which is the leading wheat producer, was ranked fifth in efficiency based on yield. The provinces of Fars and Golestan were ranked 18th and 25th, respectively. These provinces were even downgraded when GHG emissions were included, so that Fars was downgraded by three ranks and Khuzestan and Golestan by one rank. When revenue was considered instead of yield, not only were the ranks of the main wheat-producing provinces not improved but also Khuzestan was downgraded from 6th to 14th. This shows the serious need for cost management in this province as one of the most important regions of irrigated wheat production in Iran. On the other hand, the inclusion of environmental impacts resulted in the downgrading of Fars by three ranks, showing the poor condition of this key irrigated wheat-producing region in terms of environmental issues.

Regarding rainfed wheat production too, the provinces of Kurdistan, Golestan, East Azerbaijan, and Kermanshah, which are some of the main producers, were not optimal. Since less exogenous inputs, e.g., chemical fertilizers, are applied to rainfed wheat farms than to irrigated farms, rainfed farms have lower emissions, so the inclusion of the emissions did not change the ranking of the provinces significantly. Also, the improved ranks of Kermanshah and East Azerbaijan as two main rainfed wheat-producing provinces with the inclusion of gross income as an output imply the better management of production costs in these provinces versus other regions. The improved ranks of the provinces of East Azerbaijan, Isfahan, and South Khorasan in eco-efficiency also reflect their better management of the environmental impacts of this crop in these regions.

Table 7.The cross-efficiency and ranking of rainfed wheat production (revenue as the desirable output)

Province	Cross-efficiency	Rank	Eco-efficiency	Rank
Markazi	0.1332	18	0.1105	18
Gilan	0.3739	7	0.3380	7
Mazandaran	0.2157	15	0.1711	15
East Azerbaijan	0.2265	14	0.2054	12
West Azerbaijan	0.2997	9	0.2703	10
Kermanshah	0.2289	13	0.2049	13
Khuzestan	0.0662	21	0.0680	21
Kerman	0.5933	3	0.5473	3
Isfahan	0.2860	10	0.2729	9
Kurdistan	0.2100	16	0.1694	16
Hamadan	0.2435	12	0.2045	14
Chaharmahal and Bakhtiari	0.3439	8	0.3155	8
Lorestan	0.2705	11	0.2420	11
Ilam	0.1551	17	0.1448	17
Kohgiluyeh and Boyer-Ahmad	0.8208	1	0.7689	2
Zanjan	0.4579	5	0.4119	5
Semnan	0.1174	19	0.1040	19
Tehran	0.4832	4	0.4616	4
Golestan	0.1121	20	0.0871	20
Ardabil	0.4226	6	0.3801	6
Qom	0.0017	23	0.0196	23
South Khorasan	0.7695	2	0.8090	1
North Khorasan	0.0205	22	0.0233	22
Markazi	0.1332	18	0.1105	18
Gilan	0.3739	7	0.3380	7
Mazandaran	0.2157	15	0.1711	15
East Azerbaijan	0.2265	14	0.2054	12
West Azerbaijan	0.2997	9	0.2703	10
Kermanshah	0.2289	13	0.2049	13
Khuzestan	0.0662	21	0.0680	21
Kerman	0.5933	3	0.5473	3

Conclusion

Although the amount of production and cultivated area of different crops are the main factors guiding policies and plans in the region, the optimal use of resources and the environmental impacts of production should not be overlooked. The simultaneous consideration of all these factors can be a more comprehensive and rational guideline for production policymaking and planning. Unexpectedly, provinces with higher cultivated areas and production were not ranked higher in efficiency. It seems that production inputs are not consumed optimally in these regions. This is similar to previous studies according to which high production area and yields will not necessarily lead to higher efficiencies (Graubner and Ostapchuk, 2018; Malana and Malano, 2006; Shahnavazi, 2017; Shahnavazi, 2020). Regarding wheat, this can be ascribed to the key role of wheat in crop rotations, soil depletion, the outbreaks of wheat-specific pests and weeds, regional differences, and some factors beyond the control of the study (Graubner and Ostapchuk, 2018).

Although the present research focused on studying the status of different provinces of Iran in production by considering environmental impacts, it appears that the efficiency score of the regions was decreased due to their higher cultivated area, inattention to crop rotations, and the cultivation of less fertile lands. In addition, the extensive cultivated area of the crops in these provinces may limit expert advice, extension services, and face-to-face training and render them less effective. So, given the low rank of the key wheat-producing provinces, it is recommended to conduct an in-depth analysis to identify the factors influencing the production efficiency of these provinces. As such, it will be possible to tackle the weaknesses and take measures to increase production, alleviate harmful environmental impacts, and finally, ensure sustainable food security.

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