Economic evaluation of the climate changes on food security in Iran: application of CGE model

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Abstract
The present study aims to examine the economic impact of changing climate variables on two components of food security in Iran: availability and access to food. Wheat and rice, the two most important foods in the country, were considered representatives of food security. A CGE model was developed to achieve the research goals. In this context, a stochastic model based on Monte Carlo simulation was used to provide three scenarios (best, average, and worst) indicating probable changes in climate variables. It is important to model the problem of changing climatic variables for irrigated crops, as groundwater resource depletion and restrictions on extraction from Iranian aquifers reduce planted areas and yields. Therefore, this study applies this model to both rain-fed and irrigated crops, whereas studies in the literature only evaluate rain-fed crops. Food security will face serious challenges as food supplies, and consumption of goods and services are declining in average and worst scenarios, according to findings. Consequently, the negative impact of climate change on food security and people’s livelihoods requires a review of the policies implemented within the country. Effective solutions include research and development to introduce drought-tolerant varieties and adopt appropriate strategies to adapt to climate change. Improving the incomes of farmers is one solution to mitigating the impacts of climate change.

1 Introduction
Climate change and its continuation have been accepted as a serious issue around the world (Mendelsohn 2009). The most important consequence of this phenomenon is a change in the amount and pattern of precipitation (Sassi and Cardaci 2013). Although different economic sectors are affected by climate change, agriculture is largely dependent on climate as the main determinant of the location and production inputs of agricultural activities (Lizumi and Ramankutty 2015). Since water and temperature are the two main factors in the functioning of the physiological systems and in plant growth (Raza et al. 2019; Hatfield and Prueger 2015), changes in temperature and precipitation patterns directly affect agricultural activities. The agriculture sector is known to be the main source of food supply and food security (Pawlak and Kolodziejczak 2020; Hatfield and Prueger 2015). Therefore, climatic variables affect the amount of production (food availability) and also the human and physical capital determining access to food. These are of great importance in arid and semi-arid countries, such as Iran, which is located at mid-latitude with a particular climatic situation. More than 80 percent of the country is located in arid and semi-arid regions. The average annual rainfall in Iran is about 250 mm (mm), less than a third of the global average annual rainfall (Ministry of Agriculture-Jahad of Iran 2020). According to forecasts by the Intergovernmental Panel on Climate Change (IPCC), temperatures will increase by 1.5 to 4 degrees by 2100 and rainfall will decrease by 10 to 40% depending on different regions in Iran. This has been identified by the IPCC as a serious challenge for the production of strategic crops such as cereals that are expected to decline in yield (IPCC 2007).

According to the data provided by the Ministry of Agriculture-Jahad of Iran 2020, the highest level of cultivation among the country’s crops belongs to the cereal group (71.2%), of which the most important crops include wheat...
with about 69% of the cultivated area. Rice is another grain that makes up an important part of the Iranian grain diet (14% of grain consumption in 2020). These two products are considered in food security because of their importance in the Iranian food diet and also because of the existence of their separate accounts in the input–output table published by the Statistical Center of Iran, which is the basis for the design of the Social Accounting Matrix (SAM) for this study.

Food security was defined at the 1974 World Food Summit as follows: availability of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices at all times. In 1983, FAO expanded its concept to include ensuring that vulnerable people have access to available supplies and ensuring that all people at all times have both physical and economic access to the basic food that they need. In 1986, the World Bank’s influential report “Poverty and Hunger” focused on the temporal dynamics of food insecurity. This concept of food security is further elaborated in terms of access to all people at all times to enough food for an active, healthy life. In the mid-1990s, food security was recognized as a significant concern, spanning a spectrum from the individual to the global level. The UNDP Human Development Report 1994 promoted the construct of human security, which encompasses several dimensions, of which food security is only one. This concept is closely related to the human rights perspective on development that, in turn, has influenced discussions of food security. The 1996 World Food Summit adopted an even more complex definition: Food security at the individual, household, national, regional, and global levels is achieved when all everyone at all times has physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life. This definition is again refined in the State of Food Insecurity 2001, in which food security is a situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. This new concept emphasizes consumption, the demand side, and the issues of access by vulnerable people to food and focuses on the entitlements of individuals and households. This definition deals with various elements and dimensions, the most important of which are the four elements of “food availability,” “access to food,” “utilization,” and “sustainability.” Changes in climate variables affect both elements of food security (i.e., food availability and access to food) by affecting agricultural production and prices as well as the incomes of people who are dependent on agricultural activities. These two elements of food security at the national level are considered in this study because of their direct impact on the agricultural sector.

According to a report by the Food and Agriculture Organization of the United Nations (FAO) in 2017, Iran is one of the countries with moderate food security conditions. Given the country’s climatic conditions, there is no guarantee that these average conditions will remain stable and not change toward the critical state, although food insecurity has an adverse effect on the health, learning, and economic development of society. Therefore, this study aims to investigate the economic impacts of climate change (effect of precipitation and temperature) on the two elements of food security – food availability and access to food – in Iran.

In recent decades, studies have been multiplied to assess the economic impact of climate change on the agricultural sector and its consequences on food security using different methods, including econometric models, mathematical programming models (partial equilibrium), and computable general equilibrium (CGE) models. However, most of the studies conducted in Iran have investigated the effects of climate change on crop’s yield and production, for example, the study by Vaseghi and Esmaili (2008), which uses the Ricardian method to measure the economic impact of climate change on wheat in Iran. The results show that an increase in temperature and a decrease in rainfall over the next 100 years will lead to a 41% decrease in the yield of wheat in the country. Hosseini et al. (2014) studied the impact of climate change on the agricultural sector in the ZayandehRood watershed using a partial equilibrium method. The results of the positive mathematical planning model show that as a consequence of these changes, the gross profit of agricultural products in this basin will decrease by 18% over the next 30 years. It seems that the assessment of the economic impact of climate change and weather variables on food security and specifically on two dimensions of availability and access to food has received less attention from domestic researchers. This study is the first to attempt to fill this gap in the literature comprehensively and in the form of a CGE model for assessing climate change for food security. However, many studies around the world have examined this phenomenon from the economic perspective of food security, such as Alcamo et al. (2007), Winston et al. (2010), Sassi and Cardaci (2013), Chakrabarty (2016), Yadav et al. (2018), and Kogo et al. (2020). These studies used different approaches such as the Ricardian method, the partial equilibrium model, and the general equilibrium model (CGE) to study climate and food security issues. But the CGE assesses the problem across the economy to the model linkage between climate, agricultural, and economic variables, as well as links between different sectors of the economy versus other models. Accordingly, this paper uses the general equilibrium model (CGE) developed by Lofgren et al. (2002) at the International Food Policy Research Institute (IFPRI) in this issue based on the 2011 SAM for Iran (based on the latest input–output tables published by the Statistical Center of Iran). In addition, it uses a stochastic component predicted by a Monte Carlo simulation to simulate the...
impact of possible change on climate variables (precipitation and temperature). This method is contrary to the approaches used in the literature that have obtained precipitation models from general circulation models. Thus, the stochastic method predicts the probable mean of the climate variables and their extreme values, with a probability of 90%. Indeed, the stochastic approach considers the probability of the impact of a change in the climate variables. In fact, this paper used a CGE model with stochastic components, as studied by Harris and Robinson (2001) and Sassi and Cardaci (2013). However, with regard to these analyses, this paper considers this approach for both rain-fed and irrigated crops for further and more precise analysis because underground water resources have been discharged due to over-exploitation and there are restrictions on the irrigation of the products. Accordingly, as a result, in this study, the effects of climate variables on the production of irrigated areas, part of the wheat and all rice crops and the modeling of the yield response functions of these products, have also been considered, while they only assess rain-fed crops in their studies. Another novelty of this paper is that it utilizes the economy-wide general equilibrium analysis developed for Iran, going beyond the traditional methods which have determined the effects of physical variables (yield and production) cause of climate change (Vaseghi and Esmaili, 2008; Hosseini et al. 2014; Jafari et al. 2014). In addition to the issue of climate change, other recent issues such as the COVID-19 pandemic and the war between Russia and Ukraine have also led to the greater importance of food security, which shows that the availability and access to food needs more attention. This study attempted to investigate the economic variables related to these two dimensions of food security. The analysis and results of this study may contribute to inform policymakers and planners in Iran to change the political strategy, tackle climate change, and make the right decisions and actions to improve food security in Iran and furthermore to coordinate with international agreements on climate change programs.

The paper is organized as follows. The “Materials and methods” section describes the methodology by determination of productivity functions of crops in response to climate variables, stochastic model (based on Monte Carlo simulation), and CGE model. It is followed by the “Results” section discussing the achievement of the paper based on methodology. The last section concludes and recommends some policies.

2 Materials and methods

In this study, the methodology is generally presented in three sections: determining the cropping pattern, stochastic model, and economic pattern. In this way, in the first step, the functions used to simulate the effects of climate change variables on the yield of selected crops, namely, wheat and rice, are expressed as representative of food security in different agroecological areas. Then, the method of using these functions to determine the weather forecasting scenarios is presented through a stochastic model based on Monte Carlo simulation. Finally, a CGE model is developed to examine the impact of climate change variables on food security.

2.1 Cropping pattern (simulating the yield of rain-fed and irrigated crops)

In the literature, the most common way to simulate the yield of rain-fed crops is to use statistical models (Hayse 2000; Sassi and Cardaci 2013). The basis of statistical models is to use various forms of regression functions to empirically establish a relationship between crop yield and climate parameters. The functional form used to estimate the yield function of rain-fed crops was the quadratic form because it is more adapted to the nonlinear nature of the relationship between climate parameters and crop yields (Harris and Robinson 2001; Estrada et al. 2006; Eboh et al. 2012; Sassi and Cardaci 2013).

In this study, to consider the differences between different provinces in terms of both climate factors and agricultural production status, the United Nations Food and Agriculture Organization (AEZ) agricultural zoning system was used, dividing the country into 10 regions. The map of this division is specified in Fig. 1.

The climate response functions of rain-fed crops yield are specified in Eq. (1):

\[ y_{RF} = \alpha + \beta_1 RF + \beta_2 RF^2 + \beta_3 SDTem + \delta T_i \]  

where \( y_{RF} \) indicates the yield of rain-fed wheat (rice is cultivated only in the irrigated way) in the agroecological zones \( z \) at time \( t \); its unit is kg per hectare. \( RF, RF^2 \), and \( SDTem \) are climate variables representing the monthly cumulative precipitation, the square root of the monthly cumulative precipitation, and the standard deviation of the mean temperature during the growth season, respectively. \( \alpha, \beta_1, \beta_2, \beta_3, \) and \( \delta \) are the parameters that must be estimated for each region. \( T \) is a time trend variable.

The yield of irrigated crops depends on the farmers’ decision to irrigate in addition to the amount of rainfall during the growth season. In such cases, the use of the function of yield response to water proposed by the Food and Agriculture Organization of the United Nations (FAO) is effective in simulating the relationship between climate variables and the yield of irrigated crops (Evans et al. 2003; Rodrigues et al. 2009). In this function that was developed by Doorenbos and Kassam (1979), the yield response of each crop is estimated using the relationship between relative yield \( (Y^*/Y^m) \) and relative
evapotranspiration ($ET_a/ET_m$). The mathematical form of the function of yield response to water of Doorenbos and Kassam (1979) is shown in Eq. (2).

$$\frac{Y_a}{Y_m} = (1 - k_y) + k_y \left( \frac{ET_a}{ET_m} \right)$$  \hspace{1cm} (2)

where $Y_a$ is the actual crop yield value (kg per hectare) and $Y_m$ is the potential crop yield value or maximum crop yield value (kg per hectare) which is determined based on field studies and expert opinions with accepting degrees of error. $k_y$ shows the coefficients of the crop yield response to water which are published in FAO Irrigation and Drainage paper No. 33 for different crops. $ET_a$ and $ET_m$ are the actual values of evapotranspiration (i.e., the sum of effective rainfall plus irrigation water) and the potential evapotranspiration, respectively. Given the potential yield values for each crop, $k_y$ and $ET_m$ coefficients were obtained from Cropwat software; for each actual annual yield value, a value is obtained for $ET_a$ by the mathematical equation mentioned in Eq. (2).

Since the variable $ET_m$ is directly related to the growth season temperature, Eq. (2) is rewritten as the relationship between the annual $ET_m$ and the average growth season temperature ($TEM$) for each agroecological zone to explain the relationship between climate variables and crop yield using linear regression method, as follows (Hosseini and Nazari 2015).

$$Y_a = Y_m \left( 1 - k_y \right) + k_y \left( \frac{ET_a}{a + b \cdot TEM} \right)$$  \hspace{1cm} (3)

where $a$ and $b$ are the parameters that must be estimated.

### 2.2 Stochastic model based on Monte Carlo simulation methodology

After estimating the parameters of the yield climatic response functions, for each explanatory variable, a probability density function (PDF) is specified. For the amount of monthly cumulative rainfall and standard deviation of the mean temperature, references are made to the historical data of the period under study, which is 37 covering the years 1983–2019 as the changes in climate variables. It is defined by introducing a hypothesis on the lower and upper bound. According to Sassi and Cardaci (2013), this study assumed the lower bound equal to zero because the precipitation cannot be negative and the upper bound is limited but unknown to include extreme weather events. Then, based on three statistical tests measuring the similarity of historical data of variables with different PDFs, the type of PDF of the relevant variable is determined. These tests include chi-square (C-S), Kolmogorov–Smirnov (K-S), and Anderson–Darling (A-D). In this study, we defined three climate scenarios including worst, average, and best scenarios through specific
changes in the rainfall (RF) and standard deviation of mean temperature (SDTem), as shown in Table 1.

After selecting the PDF for each explanatory variable, these functions replace the explanatory variables in the climatic response function of the respective yield; then, the stochastic model is calculated assuming a repetition of 1000 times for each crop. Finally, a cumulative density function is obtained for the crop yield, which is the output of each stochastic model. This function indicates the probability that $Q_c$ (crop yield of $c$) is less than or equal to the specified value of $q_c$ (i.e., $f(Q_c) = \text{Prob} (Q_c \leq q_c)$). Accordingly, three numbers are obtained to predict the mean, upper delimiter, and lower delimiter values of the yield variable. The difference between these numbers and the corresponding number in the SAM of 2011 gives the average, best, and worst scenarios, respectively, to simulate with the CGE model.

Finally, the numbers extracted from the stochastic model for each crop are added to one to obtain a parameter as a shock entering the CGE model (Sassi and Cardaci 2013; Harris and Robinson 2001). The mathematical form is presented in Eq. (4).

$$r_{fc}^s = 1 + wh_{fc}^s; \quad c = \text{Wheat and Rice} \quad s = \text{Average, Best and Worst scenarios}$$

(4)

$r_{fc}^s$ is a parameter causing climate shock under three scenarios $s$ to produce selected crops $c$ in a CGE model. $wh_{fc}^s$ is equal to the results obtained from the Monte Carlo stochastic model.

### 2.3 Computable general equilibrium model

In this study, the main framework of the CGE model was made using the CGE model developed in the IFPRI by Lofgren et al. (2002) and Sassi and Cardaci (2013), according to the economic characteristics of Iran. The model data source is based upon the SAM compiled by this study for 2011, which was obtained using the latest input–output tables published by the Statistical Center of Iran. This matrix includes eight productive activities in five economic sectors including agriculture, food industry, other industries and mines, energy, transportation, and services producing a total of ten items of commodities and services. Table 2 shows the accounts of this matrix.

### Table 1 Definition of three climate scenarios

| Scenario        | Precipitation (mm) | Temperature (°C) |
|-----------------|--------------------|------------------|
| Worst scenario  | $0 \leq RF < 119$  | $0 \leq SDTem < 8.7$ |
| Average scenario| $119 \leq RF \leq 280$ | $8.7 \leq SDTem \leq 11.30$ |
| Best scenario   | $RF > 280$         | $SDTem > 11.30$   |

Source: research calculations

Various data sources have been used to calculate the figures in the social accounting matrix, the most important of which include the input–output tables that have been used to calculate accounts of activities and commodities; the statistical yearbook, the balance sheet and economic reports published by the Iran central bank which is used in extracting the accounts of government, enterprises, and taxes; the results of the labor force survey that has been used in obtaining the account of factors as well as the results of the urban and rural household income and expenditure survey which has been used in separating the accounts of urban and rural households. In this way, the average annual income of an urban household and a rural household has been determined according to the types of income, which can be used to separate the income of factors between households. For this purpose, the annual income of each urban and rural household is multiplied by their population in 2011 to determine the annual income of all urban and rural households. In this way, the total share of urban and rural households from all types of income is calculated.

According to Fig. 2, the component of climate change with two characteristics of rainfall and temperature affects the value-added function of the agriculture sector (Harris and Robinson 2001; Karaky 2002; Sassi and Cardaci 2013). Therefore, the value-added equation is modified. A change in the value-added of activities leads to a change in the level of activity and then a change in the quantity of commodity offered in the market, indicating the availability of food in the domestic market. The change in climate variables affects crop yields. This affects food production and availability as well as prices, leading to scarcity and food insecurity (Rademacher-Schulz et al. 2012). In fact, the reduction in the supply of food is combined with the increase in their prices; it has a negative effect on the consumer group, while about 50% of the country’s arable land is in the rain-fed sector (Ministry of Agriculture-Jahad of Iran 2020), and the employment, income, and livelihood of the population working in this sector are also affected which means reduced economic access to food.

In other words, the following structure fits the SAM and represents that production activities are the supply side of the model and the flow of market goods is the demand side of the model. Food availability is determined by the disposable amount of composite commodities that, in combination with market prices and household income, brings about economic access to food, which is represented by consumption.

Within the framework represented by Fig. 2, the component of climate variable affects the function of
value-added. Thus, the value-added equation is modified. The basic form of the function of value-added is shaped as Eq. (5).

\[ Q_{VA_a} = a^{va}_a (\sum_f \delta^{va}_{fa} \cdot QF^{va}_{fa} )^{1/\varphi_a} \]  

(5)

where \( Q_{VA_a} \) is the value-added, \( a^{va}_a \) is the parameter related to efficiency, \( \delta^{va}_{fa} \) represents the parameter of the share of factor \( f \) in activity \( a \), \( QF^{va}_{fa} \) is the value demanded of factor \( f \) from activity \( a \), and \( \varphi_a \) is the exponent of the value-added function obtained from the elasticity of the substitution of the factors of primary production (capital and labor).

The shock parameter introduced as \( rf^w_a \) represents the weather shock on the various activities of the producers of activity \( a \). It was entered into Eq. (5), affecting the other economic parameters and variables (Harris and Robinson 2001; Sassi & Cardaci 2013).

\[ Q_{VA_a} = rf^w_a \cdot a^{va}_a (\sum_f \delta^{va}_{fa} \cdot QF^{va}_{fa} )^{1/\varphi_a} \]  

(6)

All equations indicating the dimension of food availability and access to food are presented in the Appendix.

The equations are coded related to the decisions of economic agents and the equations associated with the constraints related to the economic system in GAMS software, and the initial values of variables and elasticities are determined from the SAM matrix database. The elasticity values are available in Table 9 and Table 10 in the appendix.

At this stage, the desired shock, i.e., the change of variables or parameters caused by climate change, is entered into the model, and the model is solved again to check the situation before and after the shock.

In this study, two dimensions of food security can be examined by investigating the changes in the variables of composite commodities, domestic supply, imports, and domestic demand price to show the dimension of food availability and the dimension of access to food under three climate scenarios by examining the changes in commodity price variables, the quantity of consumed commodities by household.

The data required includes a wide range of meteorological data at the level of synoptic stations including time series in the period 37 years (from 1983 to 2019) of monthly rainfall; minimum, maximum, and average monthly temperature; average wind speed; hours of sunshine per day and average monthly humidity; agricultural and cropping data in the provinces of the country include the yield of wheat (rain-fed and irrigated) and rice and production costs of some selected products to separate value-added between factors. The statistical references for collecting the mentioned data are the Meteorological Organization of Iran (2020) and the database of the Ministry of Agriculture – Jahad of Iran (2020).
3 Results

The simulation of the change of weather variables on the yield of crops has been done separately for 31 provinces of the country. But considering that the study units are agroecological zones of the country which include several provinces, they were aggregated into agroecological zones by averaging. In Table 3, the climatic characteristics of each of these zones in the period under review are reported.

According to Table 3, AEZ.2 is the most abundant rainfall agroecological zone and AEZ.6 and AEZ.9 are the least rainfall agroecological zones in the country. AEZ.1 is the coldest zone, and AEZ.7 and AEZ.10 are the warmest agroecological zone in the country. Naturally, changes in climate variables will affect the activities of the agriculture sector. The decrease in rainfall and the change in its pattern in the rain areas will reduce the yield and potential production of rainfed crops and the economic instability of production in these zones. In irrigated areas, the direct effect of the decrease in rainfall and the increase in temperature, especially for crops such as cereals that growth period coincides with the rainy season, yield reduction will occur.

3.1 Cropping pattern results (simulation of crop yield to climate variables change)

The results of estimating the climatic response functions of rain-fed wheat yield in each agroecological zone have been reported in Table 4. In AEZ.2, it is not possible to estimate the yield function of rain-fed wheat for this area due to heavy rainfall and excessive water storage in the soil. Also, according to the statistics of the Ministry of Agriculture – Jahad of Iran, in AEZ.9 and 10, the cultivation of rain-fed crops is very small. Therefore, no function was estimated for these zones.

In general, the results show that the yield of rain-fed wheat is affected by rainfall and temperature. In cold regions (AEZ.1, AEZ.3, and AEZ.5), the most important rainfall includes spring rainfall, especially in May and June, and then autumn rainfall, especially in November. The reduction in these rainfalls has a negative effect on the yield and production of this crop. For the southern regions of the country with tropical climates (AEZ.7, AEZ.8, AEZ.9, AEZ.10), the rainfall of the winter months is more important. Also, the temperature of the warm months and the late growing season...
of this crop are also important for these regions, and their increase has a negative effect on the yield of wheat. Table 5 presents the potential yield values \(Y_m\), yield sensitivity coefficient to evapotranspiration \(k_y\), and values of coefficients \(a\) and \(b\) for irrigated wheat based on the Doorenbos-Kassam equation in each of the agroecological zones of the country. The values obtained for coefficient \(b\) indicate an increase in the water requirement of the wheat crop per unit increase of temperature.

Table 6 shows the values of these coefficients for the rice crop. The provinces producing more than 90% of the country’s rice include four zones (AEZ.2, AEZ.6, AEZ.7, and AEZ.8). Rice production in other areas was less than 10% of the total production of the country, for which the estimation of the Doorenbos-Kassam equation was avoided owing to the lack of permanent production in these areas during the study season. According to the results of Table 6, AEZ.6 has a higher value than the other zones for \(b\), which indicates an increase in the water requirement of the rice crop per unit increase of temperature. This is probably due to the hot weather in summer in this region significantly increasing the evapotranspiration of the plant.

### 3.2 Results of stochastic model based on Monte Carlo simulation

In this section, to aggregate the yield values of wheat and rice in the agroecological zones, the average production of
these crops during the period under review was used as the weight for averaging. On the other hand, since in the SAM, wheat is an account and is not separated into rain-fed and irrigated, rain-fed and irrigated wheat are also combined to obtain scenarios based on wheat yield. Table 7 shows the forecast of mean, upper, and lower yield values for wheat and rice in the whole country. As mentioned, the difference between these numbers and the corresponding actual yield of crops is the basis for calculating the shocks to the CGE model, defined in different scenarios for the model. The magnitude of these shocks is presented in Table 8.

Table 7 shows that in a normal climatic situation, the yield of wheat will be 1698 kg/ha. This figure will reach 2780 kg/ha in the best climatic conditions and 421 kg/ha in the worst climatic conditions. These predictions for the yield of rice show 3901 kg/ha for normal climatic conditions, 6283 kg/ha for best climatic conditions, and 1640 kg/ha for worst climatic conditions.

The figures inserted in the first and second columns of Table 8 show the predicted changes in wheat and rice yields compared to 2011 based on the predicted changes in climate variables. The numbers − 0.0799 and − 0.001 obtained for the wheat and rice crop in the average scenario indicate that in the normal climatic situation, the wheat yield will decrease by about 8% and the rice yield will have a decrease of 0.1%, which indicate that the prevailing weather conditions are not very favorable for these products. This situation is more prominent in the worst scenario. The results are similar to the studies by Vaseghi and Esmaili (2008), Parhizkari et al. (2014), Khaleghi et al. (2015), Ghaffari Esmaeli et al. (2018), and Eslami (2020) that reported a decrease in the yield of crops, especially cereals, due to the decrease in average rainfall and increase in average temperature in Iran.

The two columns on the right in Table 8 represent the shocks that will be applied to the basic CGE model. These numbers were obtained by inserting them in Eq. (4).

### 3.3 Results of the CGE model

#### 3.3.1 Effects of climate variables change on the dimension of food availability

This section deals with examining the consequences of applying shocks calculated on economic components including the quantity of composite commodities, domestic supply, imports, and domestic demand prices of all ten groups of commodities and services introduced in the SAM. The effect of the simulated scenarios in this study on food availability with regard to the quantities of commodities accessible in the domestic market is presented in Fig. 3. In general, the results show the effect of changes in rainfall and temperature variables on wheat and rice, which is in line with the findings of Khalilian et al. (2014), Khaleghi et al. (2015), Ghaffari Esmaeli et al. (2018), and Eslami (2020) who confirm that there is a significant relationship

### Table 5

| Agroecological zones | Potential yield \( (y_{m}) \) (Kg/h) | \( k_{j} \) | \( a \) | \( b \) |
|----------------------|-------------------------------------|----------|------|------|
| AEZ.1                | 5000                                | 1        | 282.91 | 24.99 |
| AEZ.2                | 4300                                | 1        | − 73.04 | 36.63 |
| AEZ.3                | 5500                                | 1        | 332.28 | 39.09 |
| AEZ.4                | 5100                                | 1        | 231.10 | 28.76 |
| AEZ.5                | 4000                                | 1        | 645.59 | 20.40 |
| AEZ.6                | 4900                                | 1        | − 73.57 | 79.01 |
| AEZ.7                | 5700                                | 1        | − 652.75 | 77.04 |
| AEZ.8                | 5000                                | 1        | 621.24 | 17.63 |
| AEZ.9                | 3300                                | 1        | 403.66 | 64.63 |
| AEZ.10               | 3600                                | 1        | 1839.27 | 28.25 |

Source: research findings

### Table 6

| Agroecological zones | Potential yield \( (y_{m}) \) (Kg/h) | \( k_{j} \) | \( a \) | \( b \) |
|----------------------|-------------------------------------|----------|------|------|
| AEZ.2                | 4700                                | 0.99     | − 939.77 | 69.73 |
| AEZ.6                | 5700                                | 0.99     | − 1019.41 | 77.69 |
| AEZ.7                | 4300                                | 0.99     | 276.83 | 13.46 |
| AEZ.8                | 5300                                | 0.99     | 634.47 | 18.29 |

Source: research findings

### Table 7

| Product | Mean value | Upper delimiter | Lower delimiter |
|---------|------------|----------------|----------------|
| Wheat   | 1697.67    | 2779.57        | 420.86         |
| Rice    | 3900.71    | 6283.10        | 1640/08        |

Source: research calculations

### Table 8

| Scenario            | Predicted change in yield based on predicted climate variables | Shocks |
|---------------------|---------------------------------------------------------------|--------|
|                     | Wheat  | Rice  | Wheat  | Rice  |
| Average scenario    | − 0.0799 | − 0.001 | 0.9201 | 0.999 |
| Best scenario       | 0.5064  | 0.7591 | 1.5064 | 1.7591 |
| Worst scenario      | − 0.7719 | − 0.5408 | 0.2281 | 0.4592 |

Source: research calculations
between climate variables including temperature and precipitation with the amount of production in the agricultural sector especially decrease in the supply of wheat products due to this phenomenon in Iran. The commodities that are affected by the shocks directly, namely wheat, and rice, have undergone more changes. According to the figure, the amount of wheat commodity with a 90% probability will decrease between −5.24% and −46.12%, while this amount is between −0.01% and −28.78% for rice because of a 1% decrease in average rainfall. In the best scenario, it is expected that due to an increase of 1% in the average rainfall, the increase in the amount of wheat is 30.28% and about 42.36% for the amount of rice with a 90% probability. It is noteworthy that the reason for the lower reduction effect on rice than wheat is partly due to the greater dependence of wheat on rainfall because part of the wheat commodity is its rain-fed type. Also, as seen in Fig. 3, the commodity group of other cereals, horticultural crops, and other crops show relatively more changes compared to the other groups of commodities and services. This result was stressed by Khaleghi et al. (2015) which argue that although different economic sectors are affected by climate change, this effect is more on the sectors that are more interconnected with the agriculture sector. However, the path of changes of all groups of commodities and services in the scenarios is the same.

The quantities of domestic supply of commodities and their import under three scenarios simulated in this study are reported in Figs. 4 and 5. Examining these two diagrams and comparing them, the amount of imports
of commodities is not in balance with the decrease in domestic supply. It should be noted that according to the worst and average scenarios, the decrease in rainfall has led to a reduction in the region under cultivation and lower yields in the whole country, leading to a decrease in the average production of crops. The result is consistent with the studies by Goodbody et al. (2012), Sassi and Cardaci (2013), and Gouel and Laborde (2021), who agree that food availability is expected to deteriorate significantly, driven by inadequate rainfall. Therefore, the decrease in the quantity of commodities produced in the country has led to a reduction in their domestic supply. For example, with a 90% probability, the supply of wheat decreases between −7.07% and −66.86%, and the supply of rice decreases between −0.79% and −66.64% due to an increase of 1% in the average rainfall. The reverse is true in the best scenario because, as presented in Fig. 4, wheat and rice commodities will increase by 23.07% and 33.18%, respectively. In the case of other groups of commodities and services, the best scenario indicates an increase in the domestic supply of commodities, which may lead to a reduction in the domestic price of commodities and affect its imports.

In determining the price of demand for domestic products, the quantities of domestic supply and imports, in combination with the amount of elasticity of their domestic demand substitution, are influential criteria. In the case of imports of strategic commodities such as wheat, other factors such as policies in the field of self-sufficiency in its production and the lack of import licenses can also be involved. As presented in Fig. 6, the quantity of rice imports with a 90% probability will increase between 2.08% and 38.61%. Rice is the only commodity group with increased imports due to the decrease in domestic production. Therefore, the domestic demand price of this product is expected to decrease, but according to Fig. 6, this has not happened. It seems that the reason for the increase in the price of its demand despite the increase in the amount of imports.
imports is related to the low elasticity of domestic demand substitution.\(^1\)

The change in the domestic demand price of commodities in the scenarios considered in this study is presented in Fig. 6. According to the graph, the price of rice is likely to increase significantly by 90% probability, which is between 24.68% and 108.07% (worst scenario and average scenario). Hence, an increase in its imports can be observed (Fig. 5). However, in the best scenario, owing to the increase in domestic supply, there is a possibility that the price of this product will decrease. The amount of this decrease will be 6.91%. Panahi et al. (2015) also concluded that climate change affects almost 30% of rice yield in Iran in the next 15 years and will eventually lead to an increase in its domestic demand price. Domestic demand price for wheat also shows an increase between 12.39% and 52.48% (average and worst scenario). In general, the decrease in the domestic supply of wheat and rice in average and worst scenarios increased the price of demand for these commodities in the country.

### 3.3.2 Effects of climate change variables on the dimension of access to food

Implementation of the proposed scenarios on the dimension of access to food is done by examining the status of the variables of composite commodities’ prices and the consumed commodities by a household for 10 groups of commodities and services. The data in Fig. 7 show the results of the simulation of the composite commodities price under the conditions of three scenarios. In the domestic market, the decrease in food supply under average and worst scenarios is combined with the increase in wheat and rice prices. With a 90% probability, it will increase the price of wheat between 6.94% and 34.76% and rice between 10.68% and 87.04%. The result is in accordance with the studies by Nelson et al. (2009) and Kogo et al. (2020), who express that climate change will cause price increases for major agricultural crops, such as rice, wheat, maize, and soybean. This situation has the most negative impact on consumers because their food security and living standards are endangered.

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\(^1\) The exchange rate is fixed. 1 U.S. Dollar = 11,000 Iranian Rials (based on 2011 rate).

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| SERV-C | TR-C | EN-C | OINDMIN-C | FODIND-C | OAGRI-C | HORT-C | OCROP-C | RIC-C | WHT-C |
|--------|------|------|-----------|----------|---------|--------|---------|------|-------|
| (Services commodity) | (Transportation commodity) | (Energy commodity) | (Other industries and mines commodity) | (Food industry commodity) | (Other agriculture commodity) | (Horticulture commodity) | (Other crop commodity) | (Rice commodity) | (Wheat commodity) |
| Best scenario | Average scenario | Worst scenario |
| -0.01% | -0.08% | 0.65% |
| -0.63% | -0.02% | -0.11% |
| -0.87% | -0.02% | -0.32% |
| -0.98% | -0.03% | -0.78% |
| -3.80% | 0.08% | -1.06% |
| -1.88% | 0.09% | -3.18% |
| -6.08% | 1.87% | -3.18% |
| -0.89% | -0.08% | -0.03% |
| -0.08% | 0.08% | -0.04% |
| -0.32% | 0.08% | -0.08% |
| -0.11% | -0.02% | -0.01% |
| -0.02% | -0.01% | -0.01% |
| -0.03% | -0.03% | -0.01% |
| -0.08% | -0.08% | -0.08% |
| 0.65% | 10.18% | 38.61% |

---

Fig. 5 Change in the amount of imported commodities based on scenarios and commodities. Source: research findings
Combining these conditions with the reduction of household income, especially in the rural group, a simulation of access to food is created, leading to a reduction in the consumption of all commodities for both urban and rural households. The reverse case happens in the best scenario. That is, if the scenario conditions are the best, with the improvement of production and yield of selected products, there will be a slight decrease in the price of composite commodities.

Following the decrease in the supply of commodities and, consequently, the increase in their prices, the consumption of different groups of commodities and services will also decrease. These results are in line with the findings of Pakravan et al. (2015) in Iran, who showed that in both urban and rural areas, the level of household food security index had a descending trend from 2005 to 2012. Meanwhile, in a study conducted by FAO (2015) to investigate the risks and responses of climate change on food security in several African countries, it was highlighted that both rainfall and temperature variability appear to exert a negative impact on household consumption and access to food.

According to Fig. 8, the demand for rice had the highest expected decrease for rural households. Hence, there is a decrease between −8.10% and −48.29% with a probability of 90%. Generally, this group of households has the most negative impact of simulated shocks for rice and wheat products compared to urban households (a reduction of 48.29% in rice consumption and 17.63% in wheat consumption in the worst scenario). However, for other commodities, the severity of shocks in both average and worst scenarios is imposed on the urban household. This seems to be due to the lower elasticity of demand for rice for urban households than for rural households. This is the opposite in the case of the best scenario, where there is a 90% probability for the increase of household demand from all groups of commodities and services. However, the severity of this increase is higher for wheat and rice than for other commodities. Moreover, the increase in demand for rice commodities for rural households in this scenario is higher than in urban households. Meanwhile, Raj et al. (2022) also concluded that the issue of climate change and its impact on access to food and food security is severe for rural households.

According to the theory, the level of change in the consumption level of each commodity is a function of the change level in its price and the amount of demand elasticity.
The greater the price elasticity of a product or the greater the level of change in its price level, the greater the percentage reduction in the amount of consumption of that product. Examining the diagrams in Fig. 8, it is found that the percentage reduction in wheat consumption is calculated as 35%. However, the percentage increase in its price in the worst scenario is much lower, at about 18% for rural households and 9% for urban households. This seems to be due to the low elasticity of demand for this product, which is also true for other products.

4 Conclusion

In this study, considering a computable general equilibrium (CGE) model, the economic effects of climate variables change were studied on two important food products of the country, wheat and rice, representing food security. Climate yield response functions for rain-fed and irrigated crops were used to simulate the climate scenarios. The estimated functions have affirmed a direct correlation of rainfall and indirect correlation of standard deviation of temperature with the yield of selected crops. Then, based on the Monte Carlo simulation, it was obtained climate predictive scenarios in three modes of worst, average, and best to simulate in the CGE model and compare with the baseline. These scenarios are illustrated based on a PDF (probability density function) of observed data from 1983 to 2019 with the sign of the mean and the delimiters values corresponding to a 90% probability, which it confirmed a reduction in the yield of the selected crops except in best scenario (optimistic condition).

By looking at the components relative to the dimension of food availability, it is concluded that its decline is due to a reduction in the amount of wheat and rice commodities available in the domestic market. In fact, the impact of climate change on food security through this dimension occurs due to changes in the productivity of selected products. About wheat products, this issue is significant due to the policy of reducing wheat imports. While the deterioration of
Fig. 8 The diagrams of change in urban and rural household consumption by scenarios and commodities. Source: research findings
access to food is due to households reducing consumption of commodities and services due to rising prices. The decrease in private consumption in worst and average scenarios could be a sign of economic inefficiency under these conditions.

This paper has clearly been worked to examine food security in Iran under climate change. Because the current policy approach about climate change needs to be reviewed and reformed. Results achieved suggest policymakers to work to maintain and increase the production of strategic crops such as wheat and rice. Among the effective solutions are more research and developments to introduce drought and heat-resistant cultivars. Maybe changing the planting date of such crops to prevent their growth period from adapting to moisture stresses as much as possible can be considered as a simple solution. Adopting appropriate strategies compatible with climate change is also recommended, including the use of modern irrigation systems, low-volume irrigation methods, and improving the pattern of cultivation, improving farmers’ incomes, and developing the food industry system. It is also recommended that the government should pay special attention to the phenomenon of climate change and its effects on food prices in the country’s macro-planning, especially food inflation targets. Finally, by more disaggregation of accounts in SAM, it will be more beneficial to investigate the impact of weather variables change on food security. However, due to the lack of necessary data in this study, the goods and services were separated into ten groups.

### Appendix

The basic form of the function of value-added is shaped as Eq. (7).

\[
QVA_n = a_n^{va}(\sum_{f} \delta_{fa}^{va} \cdot QF_{fa}^{va})^{\frac{1}{p}}
\]  

(7)
where $QVA_a$ is the value-added, $a^{ac}$ is the parameter related to efficiency, $\delta^a$ represents the parameter of the share of factor $f$ in activity $a$, $QF^a_i$ is the value demanded of factor $f$ from activity $a$, and $\rho^a_c$ is the exponent of the value-added function obtained from the elasticity of the substitution of the factors of primary production (capital and labor).

Equation (8) denotes the activity production function with CES technology. This relationship relates the level of $QA_a$ activity with the CES function to the total value-added $QVA_a$ and the total $QINTA_a$ intermediate inputs.

$$QA_a = a^a(\delta^a \cdot QVA_a^{-\rho^a} + (1 - \delta^a)QINTA_a^{-\rho^a})^{-\frac{1}{\rho^a}}$$ (8)

where $QA_a$ is the level of activity $a$, $a^a$ is the parameter for efficiency, $\delta^a$ shows the shared parameter of each factor of production, and $\rho^a$ denotes the exponent of the CES function, which is obtained from the substitution elasticity of the factors of production.

Equation (9) shows the total quantities of commodity $c$ produced by all activities, which is a CES function of the commodities $c$ produced by different activities.

$$QX_c = a^{ac}(\sum_{a \in A} \delta^{ac} \cdot QVA_a^{-\rho^{ac}})^{-\frac{1}{\rho^{ac}}}$$ (9)

in which $QX_c$ is the quantities of commodity $c$ produced by all activities, $a^{ac}$ is the transfer parameter of the function, $\delta^{ac}$ denotes the parameter of the share of variables in the function, and $-\rho^{ac}$ shows the exponent parameter of the total output function derived from the substitution elasticity between the produced commodity $c$ through different activities.

The domestic-produced commodities and services presented in Eq. (9) are either sold domestically or exported abroad. This assignment by the CET$^3$-type function is as follows.

$$QX_c = a^c(\delta^c \cdot QE^{c} + (1 - \delta^c)QD^{c})^{-\frac{1}{\delta^c}}$$ (10)

where $a^c$ is the transfer parameter of the function, $\delta^c$ is the parameter of the share of commodities in the function, and $\rho^c$ is the exponent parameter of the CET function obtained from the elasticity of substitution between domestic sales and exports. It indicates an incomplete substitution between two commodities. $QE$ and $QD$ also represent the amount of exports of commodities and the amount of domestic sales, respectively.

The above-mentioned domestic-produced commodities are combined with imports to produce a commodity called a composite commodity, known as the Armington function, that there is an incomplete substitution between domestic commodities and similar imported commodities, that there is an incomplete substitution between domestic commodities and similar imported commodities.

$$QQ_c = a^c(\delta^c \cdot QM^{c} + (1 - \delta^c)QD^{c})^{-\frac{1}{\delta^c}}$$ (11)

where $QQ_c$ represents the quantity of composite commodity $c$; the other parameters used in this function have maps similar to the previous CET function. Equations (12) and (13) show the demand functions for domestic productions and imports.

$$QM_c = \left(\frac{a^c \cdot QM^{c} \cdot PQ_c}{PM_c} \right)^{-\frac{1}{\gamma}} \cdot QQ_c$$ (12)

$$QD_c = \left(\frac{a^c \cdot (1 - \delta^c) \cdot PQ_c}{PDD_c} \right)^{-\frac{1}{\gamma}} \cdot QQ_c$$ (13)

In this section, the domestic demand price and the price of composite commodities are presented. Equation (14) denotes the domestic demand price of commodities.

$$PDD_c = PDS_c + icd_c$$ (14)

$PDDc$ indicates the demand price of commodity $c$ which produces and sells domestically, $PDS_c$ represents the supply price of commodity $c$ which produces and sells domestically, and $icd_c$ is the sales and shipping tax costs.

Equation (15) shows the price of $PQ_c$ composite commodities as a weighted combination of the price of commodities sold domestically ($PDD_c$) and the price of imports ($PM_c$). The weights of this equation are the quantity of composite commodities ($QQ_c$), the amount of commodities sold domestically ($QD_c$), and the amount of imported commodities ($QMC$). This price is at the demander level owing to the sales tax and shipping costs.

$$PQ_c = QD_c \cdot QQ_c + (PDD_c \cdot QQ_c)$$ (15)

Finally, assuming that each household maximizes the Aston-Gray utility function concerning its consumption expenditure, the result of the first-order condition is a linear expenditure system (LES) function, indicating that the expenditure is linear. Household consumption is related to the total income. The LES demand function of household consumption is shown in Eq. (16).

$$QH_{ch} = \gamma^m_{ch} + \frac{\beta^m_{ch} \cdot (EH_h - \sum_{i \in C} PQ_c \cdot \gamma^m_{ch})}{PQ_c}$$ (16)

where $QH_{ch}$ is the amount of commodity $c$ consumption for household $h$, $\gamma^m_{ch}$ denotes the amount of minimum commodity
c subsistence consumption for household \( h \), \( \beta_{ch}^{m} \) is the consumption expenditures share of commodity \( c \) for household \( h \), and \( EH_h \) represents the disposable household income.

At this stage, the desired shock, i.e., the change of variables or parameters caused by climate change is entered into the model, and the model is solved again to check the situation before and after the shock. The shock parameter introduced as \( r_{f} \) represents the weather shock on the various activities of the producers of activity \( a \). It was entered into Eq. (7), affecting the other economic parameters and variables (Harris and Robinson 2001; Sassi & Cardaci 2013).

\[
QVA_a = r_{f} \alpha_a^n \sum f \delta_{fa} QF_f \beta_a \alpha_a^{\frac{1}{n}}
\]  

(17)

Elasticity

To calculate the elasticities, which are important information required in the CGE, other studies such as Reinert and Roland-Holst (1992), Salami (1998), and Javanbakht (2010) have been used.

Data Availability

The image supporting Fig. 1 is publicly available in the Meteorological Organization of Iran, available at http://eamo.ir.

The data supporting Table 2 is obtained using the latest input–output tables published by the Statistical Center of Iran, available at https://www.amar.org.ir.

The data supporting Tables 3 and 4 are obtained using the Meteorological Organization of Iran and the database of the Ministry of Agriculture – Jahad of Iran. Available at https://www.maj.ir/Index and http://eamo.ir.

Code availability

The equations coded in Gomez software are related to this paper and calculated by the authors and are not available to the public.

Declarations

Ethics approval

The authors have no relevant financial or non-financial interests to disclose.

Consent to participate

All authors contributed to the study’s conception and design. Conceptualization: Akram Javadi, Mohammad Ghahremanzadeh, and Maria Sassi. Methodology: Akram Javadi, Mohammad Ghahremanzadeh, and Maria Sassi. Data collection and analysis: Akram Javadi, Ozra Javanbakht, and Boballah Hayati. The first draft of the manuscript was written by Akram Javadi, and review and editing was performed by Mohammad Ghahremanzadeh. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Consent for publication

All authors agree to publish this article in your journal.

References

Alcamo J, Dronin N, Endean M, Golubev G, Kirilenko A (2007) A new assessment of climate change impacts on food production shortfalls and water availability in Russia. Global Environ Change 17:429–444. https://doi.org/10.1016/j.gloenvcha.2006.12.006

Chakraborty M (2016) Climate change and food security in India. Observer research foundation, Website: www.orfonline.org/2019

Doorenbos J, Kassam AH (1979) Yield response to water. FAO Irrigation and Drainage Paper 33. Rome, p 193

Eboh E, Oduh M, Ujah O (2012) Drivers and sustainability of agricultural growth in Nigeria. AIAE (African Institute for Applied Economics). Research paper 8, First Published, January 2012

Eslami A (2020) The impact of climate change on agricultural production and food security. J Water Sustain Dev 7(4):83–87

Estrada CGF, Conde C, Eakin H, Villers L (2006) Potential impacts of climate change on agriculture: a case study of coffee production in Veracruz, Mexico. Clim Change 79:259–288. https://doi.org/10.1007/s10584-006-9066-x

Evans EM, Lee DR, Boisvert RN, Arce B, Steenhuis TS, Prano M, Poats SV (2003) Achieving efficiency and equity in irrigation management: an optimization model of the El Angel Watershed, Carchi. Ecuador Agric Syst 77(1):1–22. https://doi.org/10.1016/S0308-521X(02)00052-5

Food and agriculture organization of united nations (2015) Climate Change and Food Security, risks and responses

GhaffariEsmaeli SM, Akbari A, KashiKalaei F (2018) The impact of climate change on the economic growth of Iran’s agricultural sector: CGE model approach. Iran J Agric Econ Dev 32(4):333–342. https://doi.org/10.22067/JEAD2. V32I4. 69897

Goodbody S, Pound J, Bonificio R (2012) FAO/WFP crop and food security assessment mission to South Sudan. Food and Agriculture Organisation (FAO) of the United Nations and World Food Programme (WFP), Rome

Gouel Ch, Laborde D (2021) The crucial role of domestic and international market-mediated adaptation to climate change. Journal of Environmental Economics and Management 106. https://doi.org/10.1016/j.jeem.2020.102408

Harris RL, Robinson S (2001) Economy-wide effects of El Nino/Southern Oscillation (ENSO) in Mexico and the role of improved forecasting and technological change. TDM Discussion Papers, 83. International Food Policy Research Institute (IFPRI), Washington, DC

Hatfield JL, Prueger JH (2015) Temperature extremes: effect on plant growth and development, weather and climate extremes 10: 4–10. https://doi.org/10.1016/j.wace.2015.08.001

Hayse J W (2000) Using Monte Carlo analysis in ecological risk assessments. Argonne National Laboratory, Supported by the U.S. Department of the Navy Under Contract W-31–109-ENG-38. http://web.ad.anl.gov/ecorisk/issue/pdf/monetcarlo.pdf/2019

Hosseini SS, Pakravan MR, Eghayi M (2014) Effects of agriculture sector total support estimate on food security in Iran. J Econ Res 30(3):225–245. https://doi.org/10.22067/ JEAD2. V32I4. 69897

Hosseini SS, Nazari MR (2015) Assessing the economic vulnerability of the country’s agricultural sector to climate change. National climate change plan, third national climate change report, Environmental Protection Organizations in Iran. July 2015

Intergovernmental Panel on Climate Change (IPCC) (2007) Available on http://www.ipcc-data.org/2009

Jafari S, Bakhshi Dastjerdi R, MosaviMohseni R (2014) Studying the effects of non-oil exports on targeted economic growth in Iranian 5th development plan: a computable general equilibrium
approach. Iran J Econ Stud 3(1):111–130. https://doi.org/10.22099/ies.2014.3114

Javanbakht O (2010) The effectiveness of the growth of the agricultural sector and other economic sectors of Iran from reducing the interest rate of facilities and increasing the supply of facilities: the approach of CGE model, Ph.D. Thesis, Agriculture and Natural Resources University of Tehran, Iran, 2010

Karaky R (2002) Climate variability and agricultural policy in Morocco. PhD Thesis. Department of Agricultural Economics, Purdue University, West Lafayette

Khaleghi S, Bazazan F, Madani Sh (2015) Effects of climate change on agricultural production and Iranian economy: social accounting matrix approach. Iranian Journal of Agricultural Economics Research 7(1):113–135

Khalilian S, Shemshadi K, Mortazavi SA, Ahmadi M (2014) Investigating welfare effect of climate change on the wheat product in Iran. Iran J Agric Econ Dev 28(3):292–300. https://doi.org/10.22067/JEAD2.V010.35472

Kogo BK, Kumar L, Koech R (2020) Climate change and variability in Kenya: a review of impacts on agriculture AND FOOD SECURITY. Environ Dev Sustain 23:23–43. https://doi.org/10.1007/s10668-020-00589-1

Lizumi T, Ramankutty N (2015) How do weather and climate influence cropping area and intensity? J Global Food Secur 4:46–50. https://doi.org/10.1016/j.jgfs.2014.11.003

Lofgren H, Harris R L, Robinson S (2002) A standard computable general equilibrium (CGE) model in GAMS. Microcomputers in Policy Research, 5. International Food Policy Research Institute (IFPRI), Washington, DC

Mendelsohn R (2009) The impact of climate change on agriculture in developing countries. J Na Resour Policy Res 1:5–19. https://doi.org/10.1080/19390450802495882

Ministry of Roads and Urban (2020) Meteorological Organization of Iran, Weather and climate information section, http://eamo.ir

Ministry of Agriculture-Jahad of Iran (2020) Deputy of planning and economy. The Center of Information and Communication Technology, https://www.maj.ir/Index

Nelson GC, Rosegrant MW, Koo J, et al. (2009) Climate change, impact on agriculture and costs of adaptation. International Food Policy Research Institute (IFPRI), Washington, DC. https://doi.org/10.2499/08960295534

Pakravan MR, Hoseini SS, Salami H, Yazdani S (2015) Identifying effective factors on food security of Iranian rural and urban household. Iran J Agric Econ Dev Res 46(3):408–395. https://doi.org/10.22099/IJAEDR.2015.55514

Panahi M, Gitipajoh M, Ehsani A, Fathi A (2015) Investigating the impact of climate change on rice yield using the SWAP model. The fifth regional climate change conference, Tehran

Parhizkari A, Mozaffari MM, Hoseini M (2014) Economic analysis of climate change effects on wheat yield in Shahrood watershed. J Agric Nat Resour 18:88–100

Pawlak K, Kołodziejczak M (2020) The role of agriculture in ensuring food security in developing countries: considerations in the context of the problem of sustainable food production. Sustainability 12(13):5488. https://doi.org/10.22099/su12135488

Rademacher-Schulz C, Afifi T, Warner K, Rosenfeld T, Milan A, Eitzold B, Sakdapolrak P (2012) Rainfall variability, food security and human mobility. An approach for generating empirical evidence. Intersections, 10. United Nations University, Institute for Environment and Human Security (UNU-EHS), Bonn

Raj S, Roodbar S, Brinkley C, Wolfe D W (2022) Food security and climate change: differences in impacts and adaptation strategies for rural communities in the global south and north, Review article. Front. Sustain. Food Syst, Sec. Climate-Smart Food Systems. https://doi.org/10.3389/fsufs.2021.691191

Raza A, Razzaq A, Mehmood S S, Zou X, Zhang X, Lv Y, Xu J (2019) Impact of climate change on crops adaptation and strategies to tackle its outcome: a review 8, 2,34. https://doi.org/10.3390/plant8020034

Reinert K, Roland-Holst D (1992) Armington elasticities for United States manufacturing sectors. J Policy Model 14(5):631–639. https://doi.org/10.1016/0161-8938(92)90033-9

Rodrigues GC, Luis S, Pereira LS (2009) Assessing economic impacts of deficit irrigation as related to water productivity and water costs. Biosys Eng 103:536–551. https://doi.org/10.1016/jbiosyseng.2009.05.002

Salami H (1998) Application of a general dynamic econometric model in studying agricultural production structure: a case study of crop production in Iran. J Agric Sci Technol 23:205–222

Sassi M, Cardaci A (2013) Impact of rainfall pattern on cereal market and food security in Sudan: stochastic approach and CGE model. Food Policy 43:321–331. https://doi.org/10.1016/j.foodpol.2013.06.002

Vaseghi A, Esmaill A (2008) Investigation of the economic impacts of climate change on Iran agriculture: a Ricardian approach (case study: wheat). Journal of Agricultural Science and Technology and Natural Resources, 12 (45): 685–696

Winston HY, Alam M, Hassan A, Khan A, Ruane AC, Rozenweig A, Major DC, Thurlow J (2010) Climate change risk and food security in Bangladesh. WorldBank, 2010

Yadav Sh, Hegde V, Habibi A, Dia M, Verma S (2018) Climate change, agriculture and food security. Available on Wiley Online Library, https://doi.org/10.1002/9781119118066.ch1

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