A simulation model for wheat-related policies and food insecurity in Egypt

Miral H. Khodeir[1] (corresponding author), Hisham M. Abdelsalam[2]

[1] Operations research and decision support department,
Faculty of computers and information,
Cairo University, Cairo, Egypt
miral.h.khodeir@fci-cu.edu.eg

[2] Operations research and decision support department,
Faculty of computers and information,
Cairo University, Cairo, Egypt
h.abdelsalam@fci-cu.edu.eg

Abstract

The aim of this study is to propose a vision on how to achieve high level of food self-sufficiency in light of the available resources, expected future changes and future needs. This study defines the major driving forces that will improve the food security in Egypt based on data and economic indicators of wheat during the period (1986-2008). A system dynamics model was built to present the process of imports, demand and consumption of wheat in Egypt, through monitoring the increase in population undernourishment, and filling the gap between the desired quantity and the supply of wheat. Finally, sets of policies were formulated and suggested to improve food security in 2030, which are presented in the improvement of land management and productivity, increase of individual income, decrease of population growth, and building a strategic inventory of wheat for solving the problems of local supply.

Key words: *Food security, Food consumption, Imports, System Dynamics, Market, Land production, Agriculture*

1. Introduction

Food security is one of the most critical issues in today's world, where it occupies great importance in the light of the steady increase in population, so as the demand on major food commodities, and lack of resources (Hafez et al., 2011). It also highlights the food crisis experienced by most countries in the world (Hoddinott & Yohannes, 2002). Food problem is coincided with the emergence of other crises, including the global financial crisis along with the changes in the value of the US dollar and oil prices. This resulted in the rise of inflation rates in the world, and reflected on the continuous suffering from the rise of food prices and the decline in their global supply (Scherr, 1999).

Several international organizations and global research centers such as FAO, monitored the emergence of global food crisis and its impact on the agriculture and food situation (FAO, 2001).

A wide gap in self-sufficiency between the production and consumption of food occurred in the light of the increasing population, rising standards of living, declining of trade in food grains and high prices in the market (Gerber, 2014).

The concept of food security is based on three main pillars, food availability, food accessibility and food stability. First, food availability, which is measured by the ability of all individuals in the community to manage their food effectively according to their physical potential, economic and social policies (Pinstrup-Andersen, 2009). Second, food accessibility, which is related to the demand and food safety, and quality. It is also related to the ability of the society to provide adequate supplies of food for the population, either from domestic production or from foreign markets. And finally, food stability is the sustainability and achievement of the previous two dimensions across different periods without exposure to fluctuations or crises (Aliaga & Chaves-Dos-Santos, 2014).

The world is facing a potential crisis in terms of food security, particularly in developing countries, such as Egypt, which is threatened by the limited water resources, shrinking arable land and insufficient agricultural production. Poverty and food insecurity in Egypt both have risen significantly over the last three years, according to reports released by the United Nations Food Agency and partners (El-Laithy, 2001; UNDP, 2010).

This study is concerned with the characterization of the current situation of wheat in the domestic and the international market. There is a need to increase and improve the availability and accessibility of food for the population, and to foresee future threats to alleviate scarcity of food. The study shed light on the importance of wheat crop indicators in terms of cultivated area, production, foreign trade, wheat prices and consumption of wheat that may be the cause of food insecurity and increased the imports of wheat in Egypt. Moreover, the study sets policies for achieving food security in Egypt. It is also a complement to see Egypt in 2030, by modeling and testing the future policy options and scenarios to assess their impact on food sector.

The paper is structured in sections as follows. Introduction of food security problem and related literature work in section 2, followed by the definition of food security problem in section 3, and model description in section 4. Results are mentioned in section 5. Finally, the conclusion and future policies are drawn in section 6.

2. Background and literature review

The food issue is considered a priority in economic policy objectives in Egypt as it is one of the main pillars of national security (Hafez et al., 2011). The Egyptian government has attempted over the centuries to provide food for the Egyptian people and achieve food security, including policies to increase domestic production and import policies from (WFP, 2013). This is done alongside adopting economic and social development plans to support agricultural activities through expansion of agriculture lands, improvement of seeds, technologies, irrigation water facilities, roads and services (Lewis, 2011).

Egypt and its culture were associated with agriculture, which has been since ancient times a source of prosperity and progress (Gamal & Hoda, 2011). Agriculture in Egypt is considered one

of the most important sources of life; it contributes in achieving comprehensive and sustainable development of the society. The growing importance of agriculture for the time being is due to the large food gap which influences the national economy of the major cereal crops, and makes the problem of food security one of the most important priorities that needs to be addressed (El-Sadek, 2010).

Grain crops represent one of the strategic crops in the Egyptian agricultural sector. It is considered an essential source of energy for humans, because they contain a large proportion of carbohydrates (El-Gafy et al., 2013). It is also responsible for achieving food security for individuals and for the society. Wheat is one of the most important strategic grain crops in Egypt (Abdo, 2013), because of its economic importance for being the crop used to make bread essentially needed by the majority of population. It contributes to about 37% of the thermal needs of the consumer and about 45% of the total animal protein and about 52% of vegetable protein (Abdel Mohsen & Albahloul, 2009; Kasem, 2013).

Several factors affected food security in most of the countries. Therefore, models, discussions and researches suggested proper solutions, throughout the years in order to face the threat of hunger and starvation. In this section, the effect of the natural and human causes on food security and production is shown throughout several studies.

Land system for food production is considered the main factor for achieving food security. It includes the availability of land for agriculture, the management of land governance for stable food production, land system architecture, planning and socio ecological systems (Verburg et al., 2013). Several studies and researches applied system dynamics in explaining the feedback loops in agriculture in series of literatures (Forrester, 2007). A modeling approach based on system dynamics was presented in (Muetzelfeldt, 2010) to study the influences and relationships between agriculture, food security, environment and livelihood. It quantifies these influences and outcomes as far as possible over time, and represents it dynamically. Another system dynamics model was provided to help decision makers apply different policies in studying process of food security to handle mismanagement of resources in order to prevent future threats of hunger and poverty (Giraldo et al., 2008).

Consumption and demand were the focus of other studies. In Highland Kenya a system dynamics model was developed to study the consumption and demand of cereals, which have been increased by the growing population. The result was that both the availability and accessibility of food have been the main constraints of food security (Breisinger et al., 2012).

Population, land use, cultivation, land fertility and market sectors have been studied through feedback loops in several researches and studies (Wang et al., 2014; Ayenew, Melak Mesfin, 2014). Different Policies have also been implemented to improve food security such as improving land management.

Technologies and global trade were used as a solution in (Allouche, 2011) to examine the availability of natural resources, food and water to cover the needs of the population. As it concluded that whenever the food production increases, population increases exponentially.

To conclude, researches have studied and set policies for managing and controlling the use of agricultural lands through models that forecast production, demand and supply of wheat crops, in order to achieve food security. Global trade is considered one of the solutions for solving the problem of self-sufficiency in Egypt, which is carried out in this study. The study also forecasts the food security in Egypt in 2030 in terms of wheat prices, production of wheat and population demand. This paper will contribute to the field of studying wheat imports, production and their effect on food security in Egypt. Since the country does not follow a certain policy for producing or importing wheat, there was a need to set rules and policies for achieving wheat satisfaction.

3. Problem Definition and Objective

The paper addresses the shortage of domestic wheat supply in Egypt that is unable to meet the continually increasing population and consumption needs aligned with scarcity of arable land and water resources. Thus, there is an urgent need to import wheat, which in return will greatly influence the governmental expenditures. This paper will develop a system dynamics model to represent and simulate the food security problem of wheat in Egypt, through modeling wheat production and imports to cover population needs in order to overcome the shortage in wheat production and supply. Moreover, a set of policies related to productivity, losses of wheat, population growth and annual income of individuals will be tested within the context in order to recommend policies that could lead to higher level of self-sufficiency of wheat.

4. Methodology

System dynamics is used to represent the feedback processes and understand the complex systems' behavior over time. It is based on the structure of "stocks" which characterize the state of the system and generate the information upon which decisions and actions are based. "Flows" that determine the rate at which quantities flow into or out of the stock over time, and converters that modify the changes occurring in the model (Sterman, 2002).

In order to explain and describe the dynamics of the different factors and elements affecting the wheat production and sufficiency in Egypt, a system dynamics model was built using Vensim Software. Given the importance of the wheat crop, it is of necessity to shed light on the key components of the model, which show the evolution of the foreign trade of wheat with respect to imports, as well as the evolution of human consumption of wheat. Finally, presenting some indicators related to the wheat crop, such as the ratio of self-sufficiency, wheat gap, and the average per capita consumption.

The model was built to simulate and explore the food security process of wheat through the study of availability, accessibility and stability of food by analyzing the process of land production, population demand, market sectors and expenditures. This is done by modeling and testing the future policy options, outlined in improving land productivity, increasing individual income, minimizing losses of wheat produced and limiting the population growth that serve the decision making process by assessing the impact of policies in food sector and testing scenarios on food security.

4.1 Model Structure

The model is subdivided into four main sub-models: cultivated wheat area productivity and production, population undernourishment, imports and market sectors.

4.1.1 Evolution of cultivated wheat area, productivity and production sub-model

The food gap in Egypt is clearly represented through the inability of domestic production to meet domestic consumption of the wheat. Thus, there is a need to enhance and increase wheat production. Studies show that the cultivated area of wheat increased during the period (1986-2008), and recorded its highest level in 2008 (CAPMAS, 2014). The productivity of Egyptian wheat acres also increased slightly during the period (1986- 2008) which lead to the rise of wheat production during the same period (MALR, 2011).

A sub-model was built to validate and forecast the upcoming cultivated area, productivity and production, where the amount of agricultural production is altered by the size of cultivated area, and the productivity of each acre of land.

The cultivated Area is represented as a stock in figure 1 and is increased by a cultivation rate of an average 1.9% each year, which was estimated from the rate of increase of land yearly. The amount of wheat produced each year is also calculated through productivity of cultivated area yearly. As shown in figure 1, a reinforcing loop of the "cultivated process" is used to represent the gradual increase of cultivated wheat land yearly. The model assumes that the cultivated area is not lost and only increases with reclamation activities. Future research will consider the effect of desertification on the size of cultivated area.

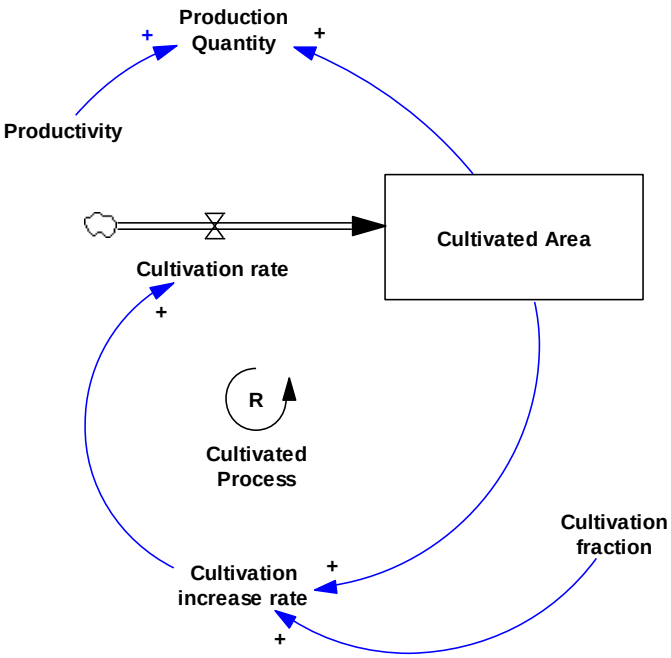

Figure 1. Cultivated Area of wheat

4.1.2 Population, consumption and prevalence of undernourishment sub-model

The population growth in Egypt is considered a unique case by all standards. Population grows at an annual rate of about 2%, leading to a speculation that Egypt will have a population of about 117 million people by 2030, thus Egypt will face food shortage in light of the limited resources of fertile land, fresh water and food supplies (Hafez et al., 2011).

Figure 2 represents a sub-model, which illustrates the interrelationship between the needs of population for wheat and their ability to purchase the required quantity for consumption. We define the growing population by the "Birth Rate" which is estimated through the population increase yearly, and the death fraction is used to define the "Death Rate" which is estimated from (Ali & Adams, 1996) to be a small fraction affected by the prevalence of undernourishment.

Due to the huge growth of population, it influenced the desire of food consumption, especially the demand of wheat. Since it is considered a major cereal crop needed by almost all the population (El-Gafy et al., 2013). Studies concluded that the wheat consumption constitutes a large share of the population's daily dietary consumption, which depends on the energy content of food. It is estimated on average to be 1700 Kcal (CAPMAS, 2014).

The capability to purchase the wheat must be considered for achieving the desired quantity, the sub-model shows the effect of purchasing power on the needed consumption of wheat through studying the average annual income of population estimated by (CAPMAS, 2014). Since the desired wheat consumption is constrained by the capability to purchase wheat, an equation is used to take the minimum value between the required amount of wheat and the amount of wheat that should be purchased yearly for an individual.

However, it is also constrained by the amount of wheat available in the inventory. The next step is converting all the quantities obtained into kilocalories to compare it with the annual desired kilocalories per person, in order to measure the satisfaction through the prevalence of undernourishment.

$$Population\ Nourished\ = \frac{Kilocal\ consumed\ per\ year}{Annual\ desired\ kilocal\ consumption\ per\ person}$$

$$Prevalence\ of\ undernourishment = \frac{Population\ Nourished}{Total\ Population}$$

This section is focused on examining the desired wheat consumption of population, wheat purchasing power, availability of wheat in inventory and how it is used to achieve food security through estimating the prevalence of undernourishment using a stock and flow structure shown in figure 2.

Causal loops were determined to explain the interactions and feedback loops of the variables in the sub-model where the first balanced causal loop is the "Undernourishment of Population", since whenever the population increases it will directly affect the increase of undernourishment leading to an increase in the death rate. A reinforcing causal loop "Desired wheat for population"

represents the needs of population from wheat in kilograms, to decrease the prevalence of undernourishment, in order to improve food security of wheat. Another reinforcing causal loop diagram "Purchased wheat", indicates the amount of wheat a person can purchase, which is affected by his yearly income. Whenever the income increases, a person can purchase wheat as much as he can, leading to a decrease in the prevalence of undernourishment.

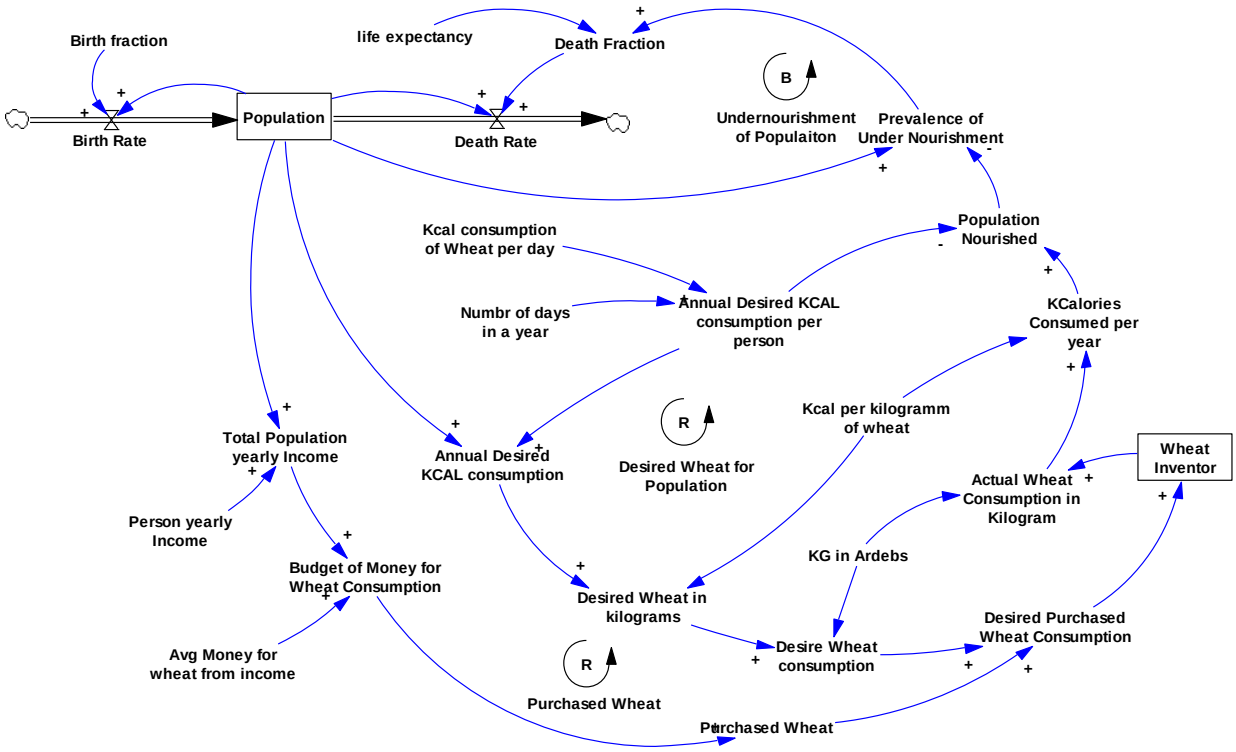

Figure 2. Food security of wheat in Egypt

4.1.3 Imports and consumption shipment sub-model

Egypt had to be a major importer of wheat in the world, in order to maintain a stock that covers the gap between wheat production and population demand (Gamal & Hoda, 2011). The sub-model was built to represent the stock of wheat, which reserves wheat for immediate consumption and in emergencies giving the government sufficient time to provide alternative supplies of wheat. A safety stock is considered in the sub-model to meet the emergencies and prevent any shortage that may occur, which is estimated to be 20% of wheat demand (personal interviews with the General Authority of ministry of agriculture and ministry of supply experts). Whenever the available stock of wheat is low or lower than the normal rates, it becomes urgent to reorder, in order to avoid any shocks in prices and markets. Moreover, other factors are also considered such as the processing time for processing or shipping an order which is assumed to be on average 1 year, (Sterman, 2002) and the inventory adjustment time which is also assumed to be 1 year to set the stock in balance, as shown in figure 3.

The sub-model shows a stock altered by the amount of wheat produced and imported in order to maintain a regular flow of wheat into the country, some of them are lost due to bad storage

system, transportation means, environmental conditions and other factors (CAPMAS, 2014). In addition, small percentages of wheat are used as seeds. The rest are used for direct consumption of the population. The consumption rate is determined by the availability of wheat in stock and the desired amount of wheat needed for the population.

The sub-model contains causal loops to show the feedback processes that take place whenever there is shortage in fulfilling population needs. The first balanced causal loop "Adjusting wheat stock" indicates the adjustment of wheat inventory whenever the inventory is lower than the population demand, consumption and domestic supply of wheat, so the amount of imports increases to balance the stock. Another balanced loop "Adjusting shipment" (Sterman, 2000), indicates the shipment rate of wheat to population, which is adjusted by the fulfillment ratio that is used to prevent shortage in inventory through reducing shipment of wheat to customers in case of low inventory available. In addition to increasing the shipment rate of wheat whenever there is sufficient or excess amount of wheat in stock.

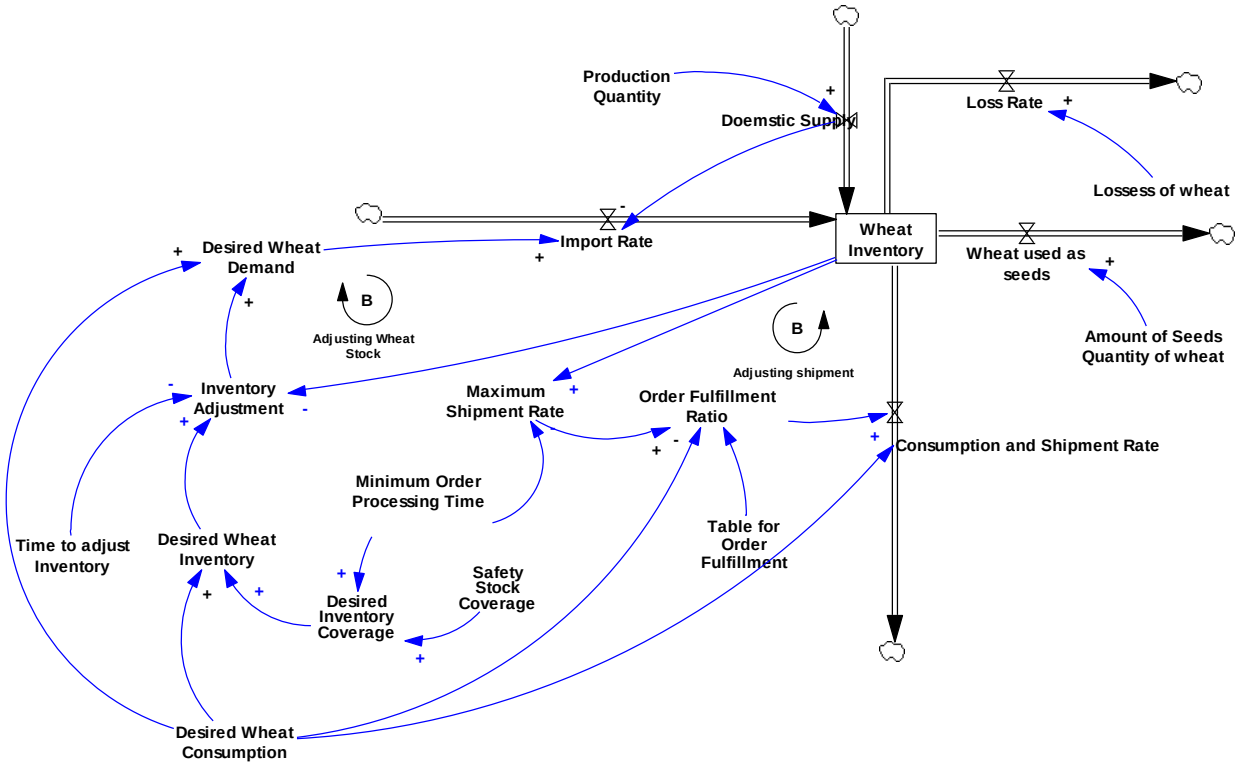

Figure 3. Wheat inventory and the process of domestic supply, imports and shipment quantities

After determining the required amount of wheat imports, a simple sub-model is created to calculate the total expenditures of wheat imports that the government should cover. The sub-model in figure 4 shows the gradual increase of imported wheat prices yearly, shown in the reinforcing loop "Prices of wheat import".

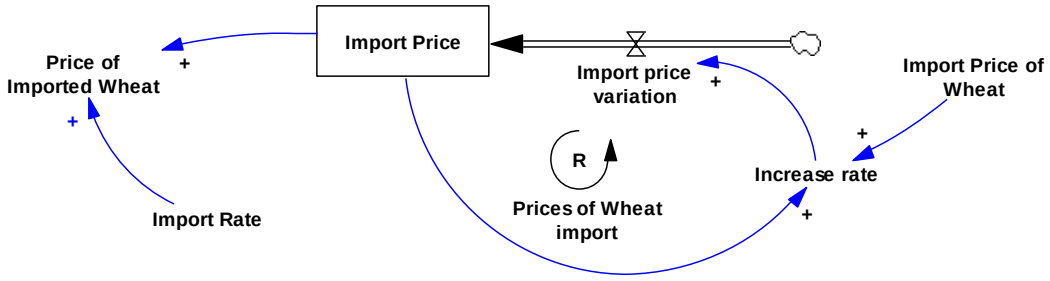

Figure 4. Prices of importing wheat per ton

4.1.4 Market and wheat prices sub-model

Spending on food and grains are considered important items in Egyptian family budget, especially wheat and wheat products, which are considered essential commodities for Egyptian people (Abdo, 2013). Changes in the global wheat prices affect its products, impact the domestic producer prices and market prices, which will consequently lead to an increase in household spending on food (Ayenew, Melak Mesfin, 2014).

Domestic prices of wheat in the market depends mainly on the producer or farmer prices from (CAPMAS, 2014), which are affected by yearly inflation and variations rates that are used to capture the changes associated with the producer price. This is due to costs of production, farming, transportation, land area rents and others, leading to gradual increase in prices yearly shown in the reinforcing loop "Producer price". Some other factors such as the markup fraction are added to the producer price to set the market prices as shown in figure 5.

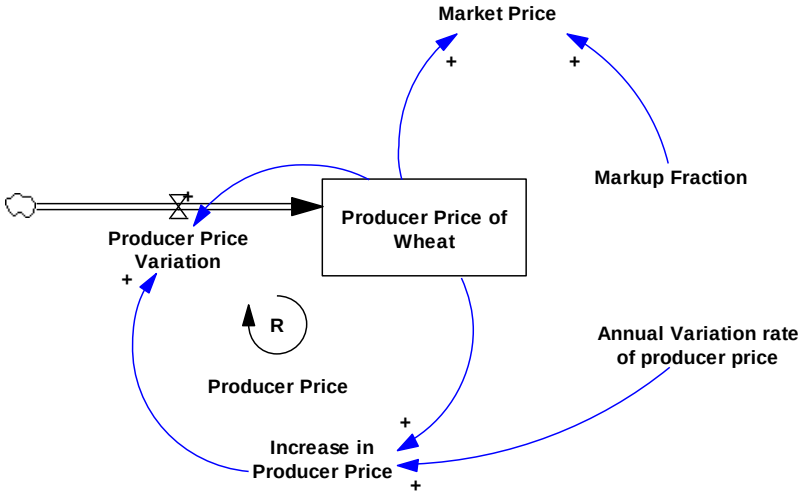

Figure 5. Producer price of wheat

4.2 Model Validation

It is important to test and validate the model to help in building the right product as per the customer's requirement and help in satisfying their needs. The model structure is validated and tested through comparing the historical data with the model results, expert reviews, and unit consistency tests. Experts from three governmental agencies: (1) Ministry of Agriculture and Land Reclamation; (2) The Information and Decision Support Center (IDSC) – the Egyptian Cabinet; and (3) Ministry of Supply and Internal Trade approved the adequacy of the model through comparing it with the real system subjectively. In addition, the model succeeded in achieving the goal of improving wheat production and food security in Egypt. The model also agreed with other researches on the shortage of wheat in Egypt and the future crisis in covering population needs (Abdel Mohsen & Albahloul, 2009; Kasem, 2013) (MALR, 2011) (Hafez et al., 2011) (CAPMAS, 2014), it also succeeded in predicting the future demand, consumption, imports and expenses of wheat.

The model has been validated during the period (1986-2008) by comparing the model results with the historical data gathered and then setting forecasts of year 2030 (CAPMAS, 2014).

In order to validate the model data, the historical data is cleansed and updated to omit the extremes and outliers found in some of the data, since they are gathered either from the Central Agency for Public Mobilization and Statistics or from expert reviews. Then smoothed by dividing the data and using the 10^{th} percentile (Q_1,Q_2,...,Q_{10}; where Q is the percentile) and eliminating Q_1 and Q_{10} from the historical data to find a consistent pattern.

5. Results and Discussions

5.1 Simulation results and future projection

Figures 6,7,8 and 9 represent the validation of different endogenous variables in thousand tons units and its projection for the next 22 years until 2030.

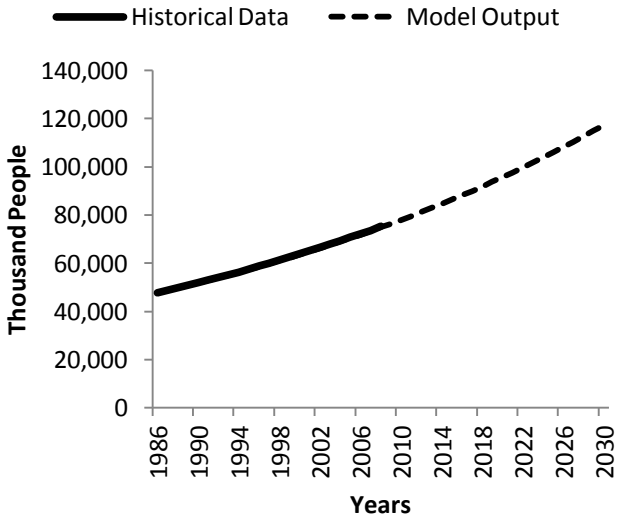

Figure 6. Population growth yearly

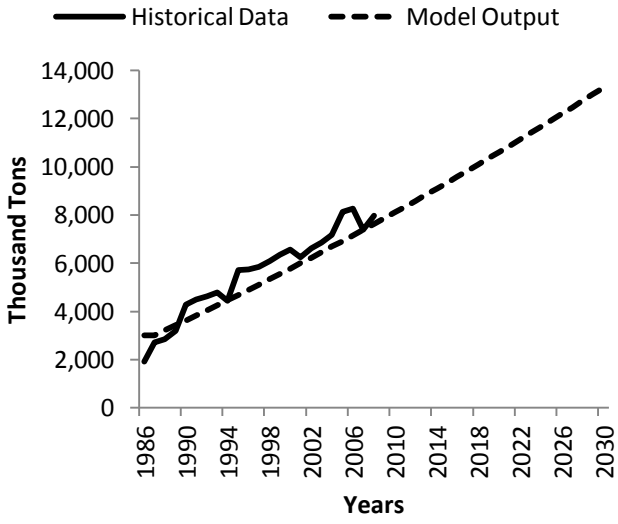

Figure 7. Production of wheat yearly

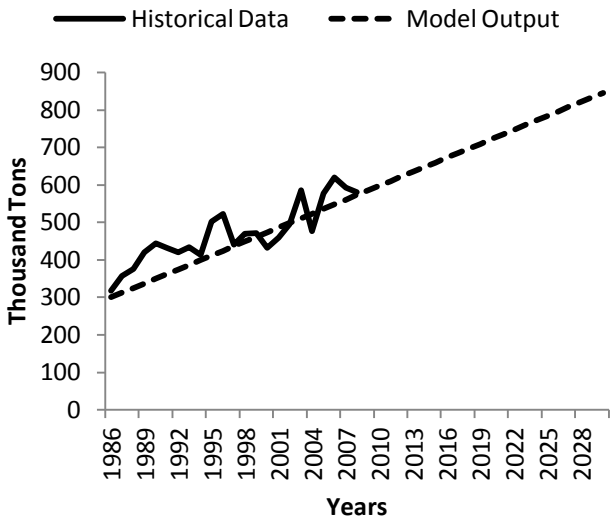

Figure 8. Amount of wheat lost

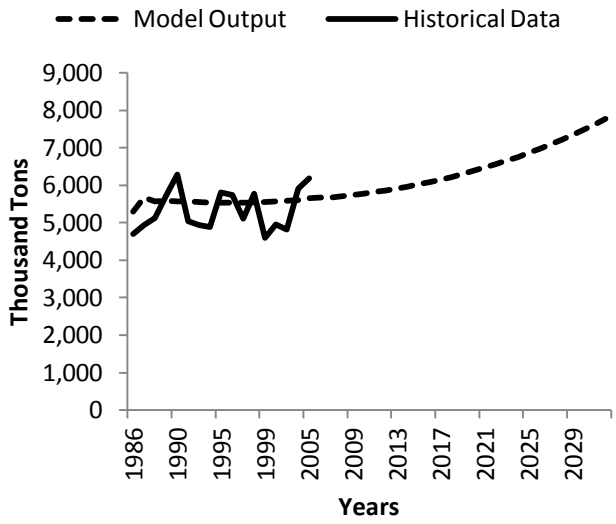

Figure 9. Wheat Imported to cover the gap between desired demand and domestic supply

Figure 6 indicates the yearly increase in population of the model compared to the historical data. Its accuracy reaches 99%. Figure 7 shows the yearly wheat production given the productivity of agricultural land compared with the historical data. Its accuracy is 93%. Figure 8 determines the losses of wheat from the amount produced and imported due to several factors mentioned before and the accuracy when comparing the model results with the historical data is 76%.
Figure 9 indicates the total imports of wheat in thousand tons, which resulted from the model and then compared with the historical data. Since wheat imports in Egypt do not follow a certain strategy, it relies heavily on expert reviews as mentioned before. It varies greatly from a one year to another according to the population needs and the quantity of domestic production. Hence, the data is cleansed and tested for validation. There was a need to manage the wheat consumption and imports, which is modeled in this study to prevent the misuse and management of wheat and to avoid the increase in prices and costs due to the yearly amount of imports from foreign countries.

To overcome the challenges already mentioned before, and reach the best possible self-sufficiency ratio of wheat needs, analysis and policies are carried out for the next 22 years until 2030 to forecast and project the future demand, supply, production, and imports. Figures 6,7,8 and 9 indicate the gradual increase of population due to the large birthrate fraction, which affects the annual demand of wheat. Figure 10 shows the amount of wheat that population can afford within their average annual income (CAPMAS, 2014). The amount of wheat purchased increased till year 2012 then gradually decreased due to the insufficiency of population income to meet the gradual increase of prices, so the quantity purchased will decrease slightly while there is a gradual increase in demand and consumption.

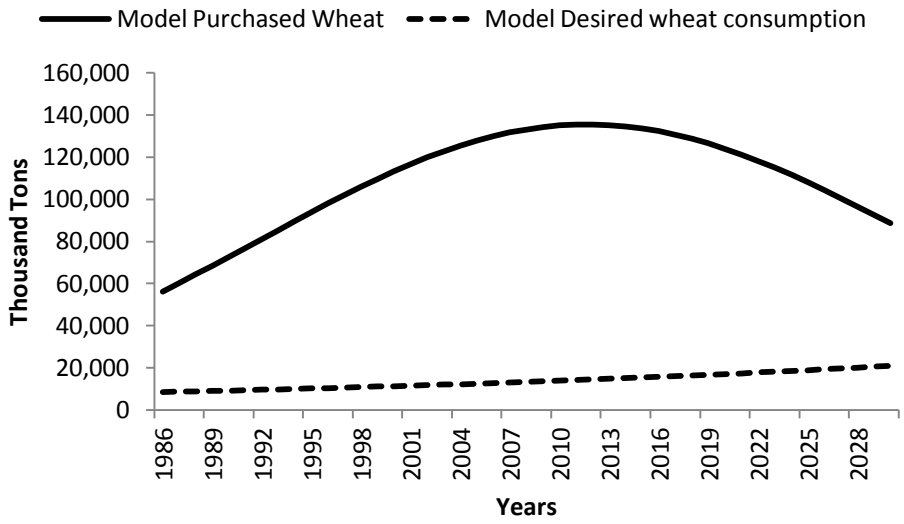

Figure 10. Amount of wheat the population can purchase given the average annual income and the desired amount of wheat for population yearly

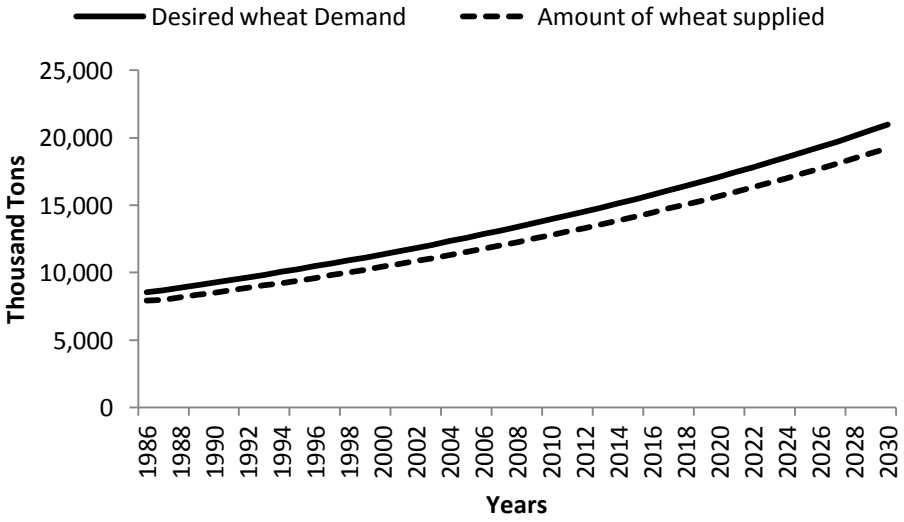

Figure 11. Fulfilling the needs of wheat for the population

Figure 11 Indicates the amount of wheat supplied to cover population needs, and the amount of desired wheat demand by the population. It determines the undernourishment ratio, which is the ratio of people who received their desired amount and those who did not, which is approximately 7.5% of the whole population.

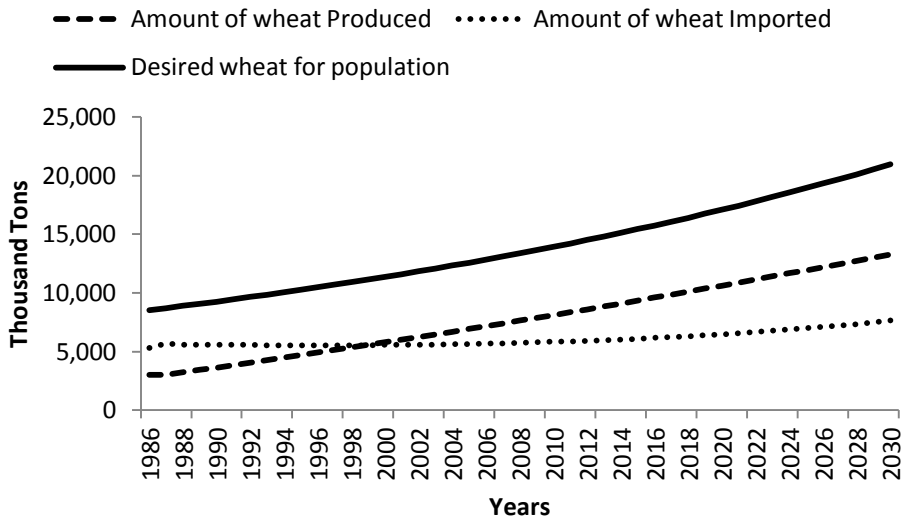

Figure 12. Amount of wheat produced and imported and amount of wheat consumed yearly

Figure 12 indicates the domestic supply of wheat which is increased gradually due to the increase in the productivity and cultivated area, while the imports increase gradually also to cover the needs of population.

5.2 Policy analysis

In the light of the outcome of the expected scenarios for the future of food security in 2030, the study recommends successive agricultural policies that lead to achieving higher levels of self-sufficiency of wheat and narrowing the gap between production and consumption to reduce imports.

a. Policies related to increasing agricultural land productivity that will lead to a decrease in imports and so, the decrease in costs of wheat imports, which will save the governmental expenditures. It depends on improving land management, supporting the agriculture inputs with fertilizers, seeds, pesticides and improving the efficiency of agricultural production by reducing the losses and optimizing the utilization of natural, human and financial resources. Figure 13 and 14 indicate the increase of productivity from 2.7 Tons/Acres to 4.5 Tons/acres and its effect on the production, the amount of imports and wheat import costs through the years 2008 until 2030. It is clear that there is a significant improvement for the wheat produced which increased by an average of 49%, which influenced the amount of wheat imported and governmental expenditures.

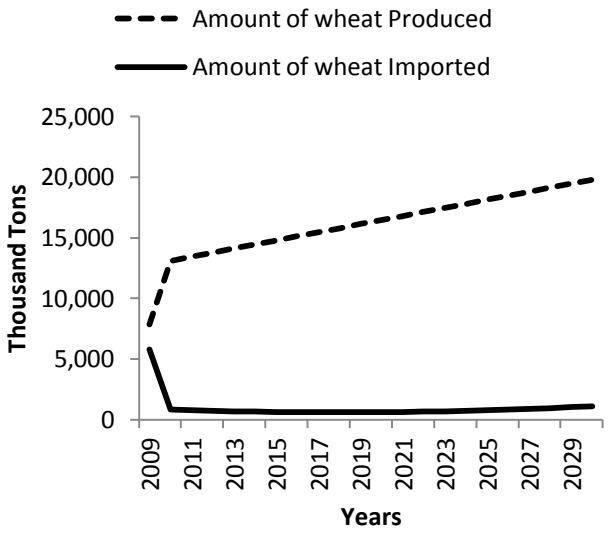

Figure 13. Production and imports after setting a productivity policy

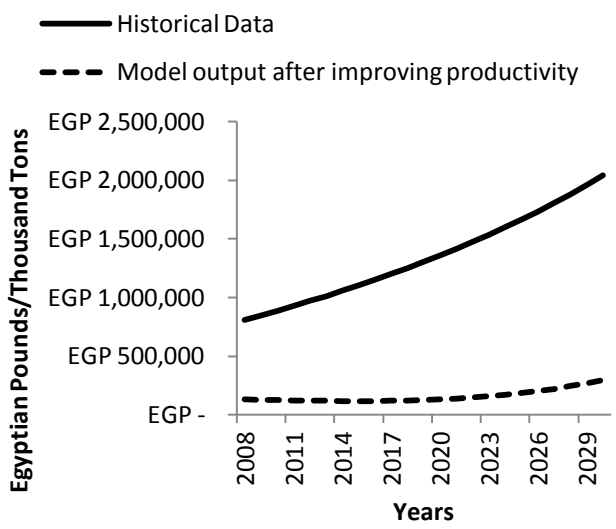

Figure 14. Expenditures of wheat imported in Egyptian Pound per thousand tons

b. Policies are applied on minimizing the losses of wheat during storage and transportation, by providing better means of transportation, paved roads in places of production and consumption, and inventories to prevent the wheat lost during storage. Figure 15 shows the decrease in the amount of wheat imports by 7.5%.

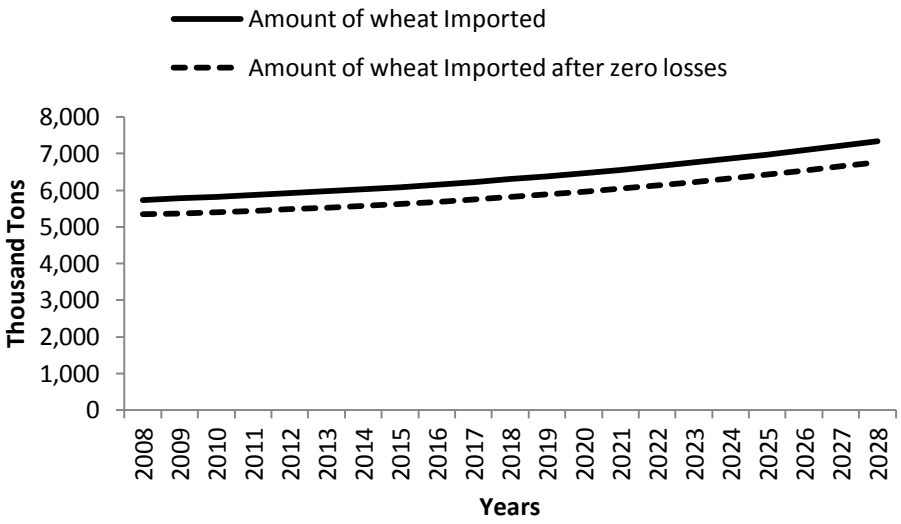

Figure 15. Amount of wheat imported before and after decreasing the amount of lost wheat

c. Policies are also applied on limiting the gradual increase of population yearly and its effect on the wheat demand. The government must provide a strong family planning program to reduce fertility so as population by personal and media awareness to maintain and enhance the issue of food security (Khalifa et al., 2000; Adamson & DaVanzo, 2001). The birth

fraction of population is estimated to be 2.8% increase each year (CAPMAS, 2014). A policy is set to decrease the birth rate of population to 2.6% yearly. Figure 16 presents the decrease in the wheat imports due to the lower demand of wheat.

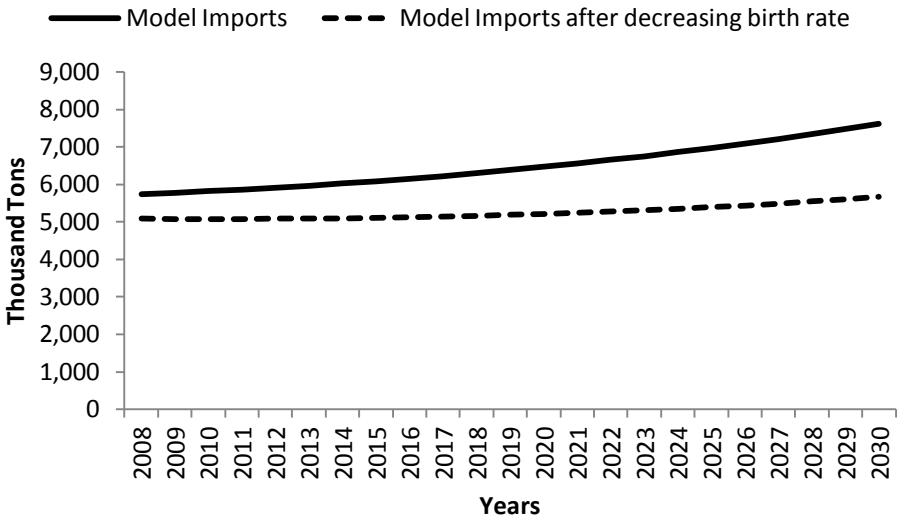

Figure 16. Imported wheat before and after changing the birth fraction of population

d. Policies are tested on increasing the average annual income of individuals, to cope with the increase of wheat prices in domestic and global markets, since it may affect the percentage of undernourishment. Figure 17 indicates the improvement of purchasing power of an individual after increasing the personal income from 2160 Egyptian Pound per month to 3800 Egyptian Pound per month (CAPMAS, 2014). The population wheat demand can then be purchased quite easily for higher satisfaction. The figure indicates the gradual decrease of the amount of wheat purchased in the future, which is due to the increase of prices.

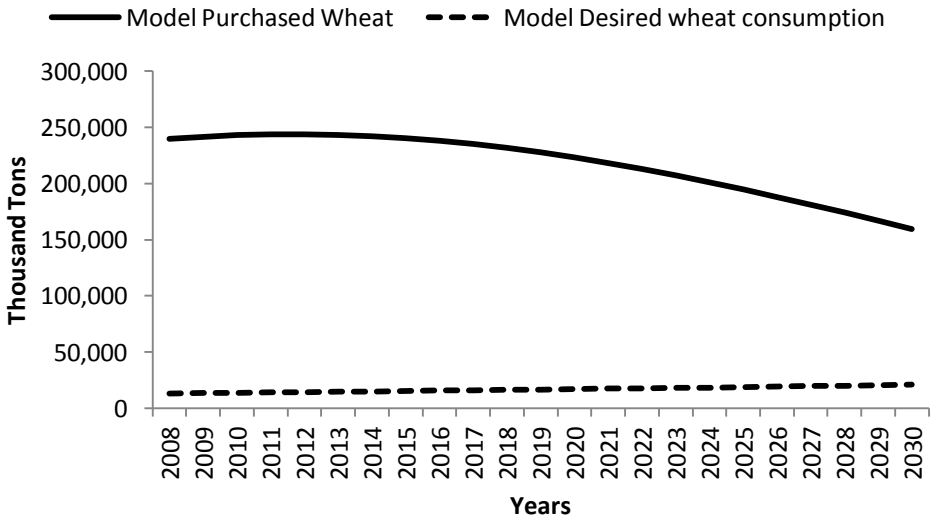

Figure 17. The improvement in the amount of purchased wheat to fit the desired wheat demand yearly

e. Policies are also applied on improving agricultural production, population birthrate and average annual income by increasing land productivity to 4.5 Tons/acres, decreasing the birth rate to 2.6% yearly, and improving the average annual income of an individual to an average of 3800 Egyptian Pound per month. Figure 18 and 19 represent the effect of these policies on amount of wheat imported, which is improved by 99%, the percentage of undernourishment, which is also improved by an average of 21% and the costs of imported wheat, which is also improved by an average of 99%.

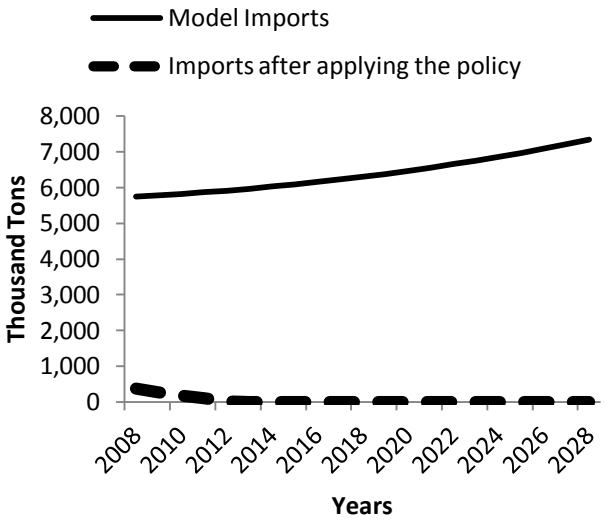

Figure 18. Imported wheat after applying the policies of birth rate, annual income and productivity

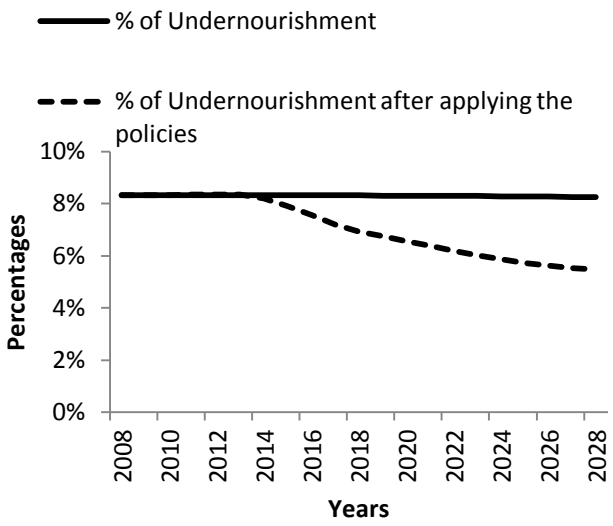

Figure 19.The percentage of undernourishment

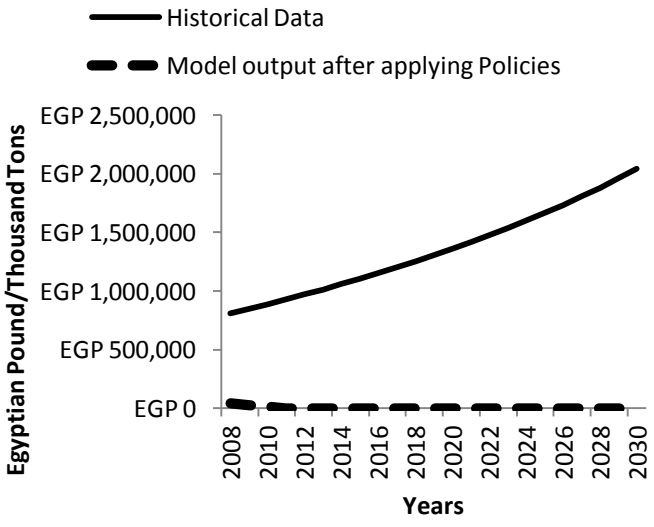

Figure 20. . Import Prices of wheat in Egyptian Pound per thousand tons before and after applying the policies

6. Conclusion and future work

Wheat is considered one of the most important strategic crops in Egypt and an important factor for food security. This paper holds several researches and deductions to prove the importance of wheat security, through conducting different models and techniques that succeed in maintaining accurate measures for the availability of wheat source to meet daily needs.
In light of the current situation of Egyptian food security, and the projected increase of population, there are many positive and negative determinants, which will contribute in the formation of food security in Egypt, taking into account the following points that have been studied in the model.

- Production process of wheat; by increasing the cultivated area, and emphasizing the importance of agricultural investment to achieve higher production efficiency, this is done by technical cooperation, transfer of expertise, agricultural research, providing efficient human resources and updated technologies to achieve the development of sustainable agricultural productivity and food security.
- Import process, which covers the gap between the domestic supply and population needs, costing the government on average 50 million Egyptian pounds per ton of wheat yearly. Thus, there is a need for a political and an economic stability factor of the local market to maintain sustainable development, by managing the factors of price increase and limiting the imports.

Further studies will be carried out focusing on the sources of water flow in Egypt, needed for cultivation that could help in the transformation of agriculture land from a non-cultivated to a cultivated land. Moreover, the factors of increasing prices of agricultural products locally will be studied. The studies will also enhance the process of imports through improving means of shipment and storage and minimizing loss of products. Finally, applying the model on various grain crops rather than wheat crop.

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References

Abdel Mohsen, S. & Albahloul, A., 2009. *The alternatives of the increase of wheat supplies and its potential risks (بدائل زيادة المعروض من القمح في مصر ومخاطرها المحتملة)*, Cairo.

Abdo, B.A., 2013. Economic study for the possibility of wheat agriculture expansion in Egypt (دراسة اقتصادية لإمكانية التوسع في زراعة القمح في مصر). Available at: http://www.publications.zu.edu.eg/Pages/PubShow.aspx?ID=9377&&pubID=19 [Accessed February 26, 2015].

Adamson, D.M. & DaVanzo, J., 2001. Population Growth in Egypt. Available at: http://www.rand.org/pubs/issue_papers/IP183z1.html [Accessed February 26, 2015].

Ali, S.M. & Adams, R.H., 1996. The Egyptian food subsidy system: Operation and effects on income distribution. *World Development*, 24(11), pp.1777–1791. Available at: http://www.sciencedirect.com/science/article/pii/0305750X96000678 [Accessed March 9, 2015].

Aliaga, M.A. & Chaves-Dos-Santos, S.M., 2014. Food and nutrition security public initiatives from a human and socioeconomic development perspective: mapping experiences within the 1996 World Food Summit signatories. *Social science & medicine (1982)*, 104, pp.74–9. Available at: http://www.sciencedirect.com/science/article/pii/S027795361300717X [Accessed January 21, 2015].

Allouche, J., 2011. The sustainability and resilience of global water and food systems: Political analysis of the interplay between security, resource scarcity, political systems and global trade. *Food Policy*, 36, pp.S3–S8. Available at: http://www.sciencedirect.com/science/article/pii/S0306919210001272 [Accessed July 30, 2014].

Ayenew, M.M., 2013. Agricultural production and food insecurity in Ethiopia: System dynamics approch. Available at: https://bora.uib.no/handle/1956/7295 [Accessed February 26, 2015].

Ayenew, Melak Mesfin, K.B., 2014. Food Insecurity in Ethiopia: Population, Food Production and Market. Available at: http://www.systemdynamics.org/conferences/2014/proceed/papers/P1273.pdf [Accessed February 26, 2015].

Breisinger et al., 2012. *Beyond the Arab Awakening: Policies and Investments for Poverty Reduction and Food Security*, Intl Food Policy Res Inst. Available at: https://www.google.com.eg/books?hl=en&lr=&id=-Fs_j3stvj4C&pgis=1 [Accessed February 26, 2015].

CAPMAS, 2014. Central Agency for Public Mobilization and Statistics. Available at: http://www.capmas.gov.eg/.

El-Gafy, I.K., El-Ganzori, A.M. & Mohamed, A.I., 2013. Decision support system to maximize economic value of irrigation water at the Egyptian governorates meanwhile reducing the national food gap. *Water Science*, 27(54), pp.1–18. Available at: http://www.sciencedirect.com/science/article/pii/S1110492913000027 [Accessed February 26, 2015].

El-Laithy, H., 2001. The gender dimensions of poverty in Egypt.

El-Sadek, A., 2010. Water desalination: An imperative measure for water security in Egypt. *Desalination*, 250(3), pp.876–884. Available at: http://www.sciencedirect.com/science/article/pii/S0011916409011825 [Accessed February 26, 2015].

FAO, A.O., 2001. The state of food insecurity in the world.

Forrester, J.W., 2007. System dynamics—the next fifty years. *System Dynamics Review*, 23(2-3), pp.359–370. Available at: http://doi.wiley.com/10.1002/sdr.381 [Accessed February 26, 2015].

Gamal, S. & Hoda, M., 2011. *Local production of wheat: Surplus in marketing, local supply and prices (تجارة القمح المحلي: الفائض التسويقي و التوريد الحكومي و الأسعار (دراسة ميدانية)*, Available at: http://www.idsc.gov.eg/IDSC/Publication/View.aspx.

Gerber, A., 2014. Food Security as an Outcome of Food Systems. Available at: http://www.systemdynamics.org/conferences/2014/proceed/papers/P1113.pdf.

Giraldo, D.P., Betancur, M.J. & Arango, S., 2008. Food Security in Development Countries: A systemic perspective. *Technology*, 1, p.15.

Hafez, W. et al., 2011. *Food security in Egypt in 2030: Future scenarios (الأمن الغذائي في مصر 2030: سيناريوهات مستقبلية)*, Available at: http://www.idsc.gov.eg/IDSC/publication/View.aspx?ID=352.

Hoddinott, J. & Yohannes, Y., 2002. Dietary diversity as a food security indicator. *Food consumption and nutrition division discussion paper*, 136, p.2002.

Kasem, A., 2013. *Economic and production efficiency of wheat agriculture in El- Beheira Governorate (الكفاءة الإنتاجية والاقتصادية لأهم أصناف القمح المزروعة في محافظة البحيرة)*, Available at: http://kenanaonline.com/users/AMFK/posts/576209.

Khalifa, M., DaVanzo, J. & Adamson, D.M., 2000. Population Growth in Egypt. A Continuing Policy Challenge. Available at: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA386347 [Accessed February 26, 2015].

Lewis, L.N., 2011. EGYPT'S FUTURE DEPENDS ON AGRICULTURE AND WISDOM. *first access on*, 16.

MALR, 2011. *List of agriculture statistics (نشرة الإحصاءات الزراعية)*, Available at: http://www.agr-egypt.gov.eg/StudiesAll.aspx.

Muetzelfeldt, R., 2010. Extended System Dynamics modelling of the impacts of food system drivers on food security, livelihoods and the environment. *CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)*.

Pinstrup-Andersen, P., 2009. Food security: definition and measurement. *Food Security*, 1(1), pp.5–7. Available at: http://link.springer.com/10.1007/s12571-008-0002-y [Accessed October 20, 2014].

Scherr, S.J., 1999. *Soil Degradation: A Threat to Developing-country Food Security by 2020?*, Intl Food Policy Res Inst. Available at: https://www.google.com.eg/books?hl=en&lr=&id=XjfyWjxEZioC&pgis=1 [Accessed February 26, 2015].

Sterman, J.D., 2000. *Business dynamics: systems thinking and modeling for a complex world*, Irwin/McGraw-Hill Boston.

Sterman, J.D., 2002. System Dynamics: systems thinking and modeling for a complex world. In *Proceedings of the ESD Internal Symposium*.

UNDP, 2010. *United Nations Development Assistance Framework for Egypt*, Available at: http://www.eg.undp.org/content/egypt/en/home/operations/legal_framework/_jcr_content/centerparsys/download_15/file.res/UNDAF 2013-2017.pdf.

Verburg, P.H. et al., 2013. Land system change and food security: towards multi-scale land system solutions. *Current opinion in environmental sustainability*, 5(5), pp.494–502. Available at: http://www.sciencedirect.com/science/article/pii/S1877343513000821 [Accessed November 27, 2014].

Wang, H.H., Wang, Y. & Delgado, M.S., 2014. The Transition to Modern Agriculture: Contract Farming in Developing Economies. *American Journal of Agricultural Economics*, 96(5), pp.1257–1271. Available at: http://ajae.oxfordjournals.org/content/96/5/1257.short [Accessed February 26, 2015].

WFP, 2013. *The status of poverty and food security in Egypt: Analysis and Policy recommendations*, Available at: http://documents.wfp.org/stellent/groups/public/documents/ena/wfp257467.pdf.