DISSERTATION

THREE ESSAYS ON FOOD SECURITY AND DIETARY DIVERSITY

Submitted by

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ABSTRACT

THREE ESSAYS ON FOOD SECURITY AND DIETARY DIVERSITY

The concern for food security is a cornerstone in the development process for every country. This dissertation is examining food security from three perspectives. First, chapter one explores the most important economic and developmental factors leading to food security and combines these factors in an index to measure the change in food security levels over time for different countries. The next chapter then uses this index to determine whether food security is related to dietary diversity. Finally, the third chapter is a descriptive study of food security in Saudi Arabia.

The first part of this research employs principal component analysis (PCA) in order to build a food security index. The objective of the analysis is to provide the variables that build a food security index and the method to weigh them, which allows a national-level comparison of countries from different parts of the world. These data will be used in subsequent parts of this research to study the association between the overall food security index and the four pillars of food security with dietary diversity at the national level in different countries. To build the index, PCA was used to evaluate the contribution of all 31 indicators of the four dimensions of food security (food availability, food accessibility, food utilization, and stability) represented in the FAO data set between 1990 and 2011. Standardized measures of different variables were used to make it easy and reasonable to form one index. The results indicate significant effects for 18 of the 31 variables as indicators of food security. Finally, all of these indicators were combined into a single measure to reflect a multidimensional index of food security for the 59 countries represented in the study.

The second chapter of this research addresses one important aspect of food security: dietary diversity. The study assumed that a heterogeneous level of dietary diversity across several countries would be related to their levels of food security. There are several indices that can be used to measure the diversity of food on a countrywide level. This chapter uses the Simpson Index to measure the energy intake diversity of six food groups (rice, wheat products, starchy roots, sugars and sweeteners, fruits and vegetables, and animal products) and the multidimensional food security index, constructed in the first chapter, to represent levels of food security. This case study uses the average data between 2000 and 2011 for 59 countries. In conclusion, these correlations and linear regression models have found that dietary diversity is not affected by levels of multidimensional food security, while the sizes of energy intake increase with levels of food security. It is important to realize that this result does not mean that the diversity of food consumption is less important; it means the tools that could contribute to improve food security do not necessarily contribute to change dietary diversity levels but only change the size of food consumption.

The third chapter is a descriptive and qualitative study of food security in Saudi Arabia. The country could reach a good standing of food security compared with other countries according to several food security measurements. This refers to several policies of the Saudi government to invest large revenues from the oil industry to achieve development in the country, with food security representing one aspect of development. In the early stages of development planning, the government targeted to guarantee food supplies and achieve self-sufficiency from agricultural products by supporting domestic agricultural production. This led to the development of domestic production and extensive use of technology in domestic agricultural production, which contributed to more production efficiency. Also, the government supported final food prices to make food easier to access for all residents of different income levels. Unfortunately, some government policies were inefficient and contributed threats to food security such as subsidizing domestic wheat production, which consumed a lot of water. Recently, the government has adopted policies to maintain sustainability in food security such as supporting domestic production for crops that consume less water, supporting overseas investment in agricultural production, increasing the capacity of wheat storage, and reducing the wastage of resources. Even so, food security in Saudi Arabia still faces several challenges that threaten sustainability, such as political instability in the Middle East, water scarcity, reliance on food imports, fluctuations and increases in food prices, food consumption habits, and population growth.

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1.1 Introduction

This research seeks to determine the factors that influence food security in different countries and to provide a quantitative index of food security that is useful for comparative studies worldwide. Dietary diversity is one of the primary factors that determine food security, and in order to study the influence of such a factor on food security, it is necessary to have a measure that represents food security. Various studies have provided indices of food security at household, regional, and national levels depending on the focus of the study. However, measures of food security at a country level are often inconsistent across countries and time periods because the different characteristics for every country and for each country from time to time. In this chapter of the dissertation, I will create a measure that takes into account the different facets of food security, which in turn will help understand food security problems and policies.

A food security index includes several indicators that are used to create a multidimensional composite measure. Most food security indicators are organized along the four major pillars of food security, as defined by the Food and Agriculture Organization (Grainger,2010): availability, accessibility, utilization, and stability. Although there are different composite indices for food security, such as the Global Food Security Index, the Global Hunger Index, and the Poverty and Hunger Index, reports using these indices and other studies do not provide measures of food security for long time periods and most countries such as what this research targets. This study will develop a new model of food security that could be used for any time in any country to measure a level of food security. Therefore, the research objective is to identify available indicators of food security across countries to include them in the calculation of a national-level food security index. Identify these indicators will be helpful for learning how different policy choices could contribute to food security development.

This research examines food security from the years 2000 to 2011 across 59 countries from Africa, Asia, North America, South America, and Europe by using new model indicators for food security. A new comprehensive food security index for these countries will be found by using available indicators in the period from 2000 to 2011.

These 59 countries face different food security issues, and they also show varying coping strategies for their food security problems. The comparison between these countries will help understand the ways or indicators that contribute to the change of food security. To produce a valid index of food security, all indicators of food security in Food and Agricultural Organization (FAO) data will be included in the current study. The construction of the index will follow six steps: (a) defining the phenomenon of food security, (b) selecting the variables, (c) dealing with missing data issues, (d) homogenizing the information, (e) weighting the information, and (f) aggregating the information.

1.1.1 Food Security and Economics

Economic factors play an important role in food security. One of the main causes of food security problems is price variation, such as the price shock in 2007/2008. Also, poor countries with small values of gross domestic product (GDP) have more issues with food security. Thus, indicators of food security issues include economic variables on the supply and the demand side. On the supply side, the indicators of availability and stability pillars represent economic variables, including production and imports. Most indicators of access and utilization represent demand side factors such as prices and income. That means that economic factors have important effects on food security at individual, household, country, and global levels.

To understand the food security index, it is important to study the effects of other economic factors that are not included in the index. Simply put, it is difficult to improve food security without knowing the effects of economic factors such as employment, age, education, and size of trade. Therefore, exploring the size of the effects of economic factors on different food security indicators gives decision-makers the understanding they need in order to make rational choices with respect of food security development in any country. The first step to deal with the food security problem is to measure its performance and to evaluate policy choices.

In addition, achieving food security is one of the most important priorities of economic and social policy-making. Economic policies could reduce the food security gap caused by other economic and noneconomic factors such as subsidies for food staples. Finally, well-being is an economic factor that could use food security index as an indicator. The trend of an overall food security index is important when examining changes in the well-being level.

1.2 Literature Review

1.2.1 Measures of food security — Composite indices

Developing a consistent measure of food security is challenging due to the complexity of the concept. There is no agreement regarding a standard definition of food security, nor are there standard metrics for food security. A lack of available data across countries for long time periods and variation in methodologies used to combine these indicators creates additional difficulty (Aurino, 2013). There are different approaches to investigating the level of food security in different countries. Some researchers use consumption conduct surveys, which ask about food sufficiency, food availability, and food access. This method is commonly used in USDA reports of food security (Keenan et al., 2001). Another approach uses the ratio of one variable or group of variables to another to indicate the level of food security with, for example, food expenditure expressed as a share of income (Pinstrup-Andersen, 2009).

Most food security research uses primary data such as a survey questionnaire of households to measure the food security level. One of these studies is the annual report from the Food and Consumer Service division of the United States Department of Agriculture. As of 1997, the household food security report of 1995 classified the food security using four categories: (a) food secure, (b) food insecure without hunger, (c) food insecure with moderate hunger, and (d) food insecure with severe hunger. The survey questions were designed to place each response under one of these categories using food consumption behavior (Hamilton and Cook, 1997).

Some researchers investigate food security by using an index because there is no direct way to compare food security across broad samples, for example, between several countries. A food security index can consist of primary data, collected in surveys, or the secondary data provided by some United Nation organizations. Matchaya (2012) used a survey to study the level of food security in Central Malawi, with dietary diversity as an approximation of food security. The results indicated that farm income, farm credit, individual age and sex, education, and consumer worker ratio were significant to determinants of the level of dietary diversity. Matchaya also mentions other indicators for food security that were not included in the study, such as underweight, under-nutrition and malnutrition incidences, levels of reported consumption, levels of reported food insecurity, and levels of production at the household level.

Calorie requirement is another indicator of food security. Farid and Wadood (2010) used calorie requirement for the assessment of household security in Bangladesh. Household characteristics and the price of rice had strongly significant effects on food security level compared to wages. Based on the data from the Survey of Program Dynamics (SPD) by the US Census Bureau (2002), Guo (2011) investigated the effect of household economic resources on food security. This researcher used income and assets to indicate household economic resources and the USDA food security scale to show food security status, and results indicated a significant relation between them. However, Migotto et al. (2006) argue that food security cannot be measured by a single indicator because it is a multidimensional phenomenon. They measure the effect of multiple indices, such as dietary diversity, household assets, and share of nonfood items in total consumption on calorie consumption and food expenditure using two separate models, to compare the effect in two countries (Albania and Madagascar).

While a multitude of indicators are consistent with the multi-dimensionality of the food-security issue, some researchers use composite indicators because they are easier to interpret in the public policy domain. Saisana and Tarantola (2002) discuss advantages and disadvantages of using a composite indicators technique. Complex or composite indicators help decision-makers by reducing complex or multi-dimensional issues, making information easy to interpret. For example, composite indices are used to rank countries by focusing on one measure rather than on many separate indicators. They can also be used to compare the performance of countries over time. One of the disadvantages of adopting composite indicators is that they might send the wrong message to decision makers if there is a weakness in the construction of the index or interpretation of the data. Also, the reduction of many indicators to a simple index could lead politicians to deal with complex issues as simple issues. Great care must be taken during different stages of building complex and composite indicators: the selection of the underlying model the treatment of missing values, and selecting the correct individual indicators and their weights (Saisana and Tarantola, 2002).

Of course, the use of an index as a composite indicator for the performance of individual indicators is not unique to the topic of food security; such indices have also commonly been used for assessment in areas such as health care, public sector performance, university performance, and policing performance. For example, Jacobs et al. (2004) measured the performance of health care systems using a multidimensional measure by introducing the annual star ratings of National Health Service (NHS) hospitals in the UK. Ten indicators were combined using Monte Carlo simulations, which is one method for developing a new composite index. Also, the composite indicators used to rank colleges and universities by U.S. News and World Report (USNWR) are generated using the principal component analysis (PCA) method (Webster, 2001). This ranking provides important information for prospective students and universities that need to evaluation. The collective score depends on 16 measures that are in seven categories used to rank colleges and universities, such as number and quality of admission applications, retention rates, enrollment measures, financial resources, operating budgets, per student expenditures, faculty/student ratios, academic reputation, alumni giving, class size, graduation rate, and other factors (Webster, 2001).

Other studies also support the use of a group of factors to form a composite index when no single indicator is appropriate. Jollands et al. (2004) used principal component analysis to develop an aggregate measure for eco-efficiency in New Zealand. The five dimensions included in the aggregate measure for eco-efficiency in this study were water pollutants intensity, energy and energy-related air emissions intensity, material intensity, land intensity, and water use intensity. Vyas and Kumaranayake (2006) classified households into socioeconomic groups using durable asset ownership, access to utilities and infrastructure, and housing characteristic variables to measure wealth in the absence of income or consumption data with principal component analysis. The composite index of socioeconomic status was used to as a measure of climate change vulnerability and resilience.

The previously mentioned papers as well as this chapter follow basically an ideal sequence of constructing composite indicators as outlined in the standard textbook on such indicators: (a) develop a theoretical model, (b) select individual indicators, (c) interpret missing data, (d) perform multivariate analysis, (e) normalize data, (f) choose weights and aggregate data, and (g) perform robustness and sensitivity tests of different steps (Peña-López, 2008). The definition of food security, in any given study, influences the indices used to measure food security, so studies differ in the dimensions of food security that are considered. As dimensions differ, different indicators are expected to be included in the index. According to the FAO definition provided by the 1996 World Food Summit, there are four main pillars of food security including, physical availability of food, economic and physical access to food, food utilization, and the stability of the other three dimensions over time.

Several studies have been conducted that combine indicators of the four main pillars of food security to produce a multidimensional index. Napoli (2011) used a multidimensional index to compare and rank food insecurity across 61 countries. The multidimensional index included 8 indicators for the availability dimension, 4 indicators for the access dimension, 3 indicators for the utilization dimension, and 5 indicators for the stability dimension. Other studies did not include indicators for the stability dimension and included only information relating to the three other pillars (availability, access, and utilization) to capture differences across 57 middle- and low-income countries (Aurino, 2013). The stability dimension was omitted because the researcher analyzed a cross-section of countries in a single year (2008), so no comparison across time was available.

One study used different factors that influence food security to categorize 175 countries (Yu, You, and Fan, 2010). Yu et al. used the following five dimensions of food security at the national level: (a) food sources or availability (production and imports), (b) utilization (consumption), (c) food distribution, (d) food trade, and (e) agricultural potential dimensions to determine food security. The five dimensions were composed of nine variables including, daily calorie intake per capita, daily protein intake per capita, daily fat intake per capita, annual food production per capita, ratio of total exports to food imports, share of urban population, soil fertility for long-term stability of food supply, length of growing period, and coefficient of variation of length of growing period. Yu et al. used factor analysis to measure food security and to categorize countries into five groups of food security (Lowest, Low, Lower middle, Upper middle, and High) depending on the food security score for each country. Also, they divided countries into subgroups based on secure or unsecure trade, and high or low soil fertility. In addition, the results indicated that there were low or high production subgroups within trade categories, and favorable climates and unfavorable climate inside soil fertility categories. The authors concluded that food security issues in developing countries are extremely heterogeneous, and they suggested that research focus on across-country studies at the same level of food security, learning from each country's experience.

Currently, there are two comprehensive indices for large countries that measure extreme cases of food security, the Global Food Security Index (GFSI) and the Global Hunger Index (GHI). Since 2011, the Economic Intelligence Unit (EIU, 2015) has issued an annual index of food security for different countries. Previously, this research center issued four annual reports of the GFSI between 2011 and 2014 across 109 developing and developed countries. This index uses 28 indicators to assess three pillars of food security. Six indicators comprise the affordability dimension, 11 indictors comprise the availability dimension, and 11 indicators comprise the quality with safety dimension. The GHI is published by the International Food Policy Research Institute (IFPRI) across regions and countries from 2006 to 2015 (Von Grebmer et al., 2014). The purpose of this index is to observe the progress of factors that affect hunger and awareness of hunger on a scale from 0 to 100, with 0 and 100 as best and worst score, respectively. Three indicators for hunger that are reflected in the GHI are undernourishment, child underweight, and child mortality, which are weighted equally in the GHI score. As of 2015, the global hunger index excluded child underweight and included prevalence of wasting and stunting in children under five to reflect the latest thinking regarding child undernutrition. The GHI scores were calculated for 120 countries in the last edition in 2015. GHI was not calculated for high income countries because of limited hunger. Also, the index was not calculated for countries that do not have a large enough dataset. Building this index included three steps that started by gathering the values of the indicators from United Nations agencies, then standardizing the scores, and finally aggregating the standardized scores to calculate the GHI for every country.

Manarolla (1989) ranked 75 developing countries according to food security levels. He evaluated food security at two levels: (a) the entire country, and (b) the household or individual level. He developed a model for food security that combined measures of the availability of food at domestic food markets and access to food by households. Four indices were used to compare food security in these 75 countries. The first index, the national food self-reliance index, incorporated average annual per capita food production and average annual per capita gross foreign exchange earnings as indictors. The second index incorporated per capita gross national product (GNP), average daily calorie consumption per capita, and the mortality rate per thousand for children under the age of five years as indicators for a household food access index. In addition, a performance index was calculated using per capita domestic food production, per capita foreign exchange earnings, and average annual growth rate of per capita GDP. Finally, a composite food security index derived from the national food self-reliance and the household food access indices was produced, which included all indicators in the other indices.

1.2.2 Food Security Variables Constructed

The two essential differences between attempts to build an index for food security are the indicators that are used and how they are measured. Measurement of the indicators includes proposing a model, weighing the indicators, aggregating the data along the dimensions of food security, and normalizing the data. Studies include different indicators depending on the availability of data for identified dimensions of food security and the specific interests or basic model of the study. A lack of available data often precludes the study of a larger sample of countries or a greater number of food security indicators. These issues create a challenge to the development of a comprehensive, multidimensional index of food security that is applicable to a broad sample of different countries (WHO, 2000–2014).

Most of studies distribute food security indicators across the four pillars of food security as defined by the FAO (Grainger, 2010) including availability, accessibility, utilization, and stability (Napoli, 2011; Santeramo, 2015). Others consider different dimensions of food security, such as affordability, availability, and quality and safety dimensions (EIU, 2015), or food consumption, production, trade, distribution, and agricultural potential (Yu et al., 2010).

Researchers usually create an index to produce a numerical value that represents qualitative variables or multidimensional concepts. There are many variables to use as a proxy for an index. Several models are useful as a basis for building a food security index. Appropriate models reduce the information from many indicators to a single index, or they are used to identify latent variables for food security that contribute to the common variance among a set of indicators. The most appropriate model for studies that seek to reduce indicators is the principal component analysis (PCA) method. Factor analysis is more relevant to the identification of latent variables (Napoli, 2011; Yu et al., 2010). Although the solutions for factor analysis and PCA are similar, they differ when there are a large number of dimensions to consider (Peña-López, 2008; Velicer, 1990). Peña-López listed the strengths and weaknesses of PCA and factor analysis. The strengths of these analyses include the representation of a set of different indicators in one index, and the identification of indicators that make large contributions to common variance across countries, indicating the relative importance of each indicator to other indicators in index. The primary weaknesses of these methods include a dependence on correlation, which may not reflect the real impact of the indicators on the measured phenomenon, the effect of any change or outliers in the data, sensitivity to small sample sizes, and small effects demonstrated by indicators that have low correlations with other indicators.

Given the complexity of measuring food security, PCA is a viable method that has been used frequently in scientific analyses that use multiple measures or dimensions to express or fit the specific definition of a variable. This method reduces data across multiple variables to a score that expresses all of the dimensions of interest. Napoli (2011) conducted a study that used PCA to obtain a food security index using multiple dimensions. Based on the four regular pillars of food security (availability, access, utilization, and stability), the researchers included 8 indicators for availability, 4 indicators for access, 3 indicators for utilization, and 5 indicators for stability for a total of 20 indicators. The actual measure was the inverse of the food security index, meaning that the value expressed food insecurity. Napoli divided the countries in the sample into four categories, according to demonstrated levels of food insecurity. The four categories are moderate, serious, alarming, and extremely alarming food insecurity, depending on the score on the index of a given country. This study compared measures of food insecurity in four different years including, 1995, 2000, 2005, and 2009. Napoli also used aggregation to compare different regions in the world. The researchers reported that a lack of available data was a problem in all four time periods considered.

Santeramo (2015) compared the steps used for different methods of building an index of food security and observed the relationships between them. The primary finding of this study was that changes in a country's ranking differ as the index changes, where the primary difference between the indices comes from the data imputation and aggregation methods used, and normalization and weighting of the indices are less significant contributors to differences between the rankings.

As such, attention to several details is required while choosing processes for weighting across dimensions, aggregation, and normalization of indicators. First, weighting techniques reflect the relative importance of indictors, and there are a number of weighting techniques that are based on statistical models. Equal weighting is one option, which means that all indicators are given the same importance in the index. Researchers use the equal weighting technique when there is a lack of theoretical knowledge or empirical evidence in an area of interest. Linear and the geometric aggregation approaches are the most common ways to aggregate the dimensions of an index. The linear aggregation approach implies there is perfect solution among dimensions, and the geometric aggregation approach gives less compensated indicators or dimensions a lower value. In conclusion, researchers need to synthesize a food security index model that incorporates several procedures to normalize indicators and produce scores on a standard scale that can be used to compare food security across different countries. The simplest normalization method is ranking indicators. Other alternatives are creating score functions, and standardizing data by computing z-scores (Santeramo, 2015).

1.3 An Empirical Model for a Food Security Index

1.3.1 Theoretical Framework

In previous research indices for non-measurable constructs have been calculated by compounding different sources of information in a weighted sum. If there are no correlations between any of the indicators, the weight cannot be estimated (Joint Research Centre-European Commission, 2008). The general index refers to several variables if there are correlations between many of them. In this case, there are many variables that are indicators for one of four dimensions of food security (availability, access, utilization, and stability) and no single one of these indicators measures the food security directly. So, one index can be calculated by combining the indicators in linear combinations, where the weight of each indicator measures the importance of this variable to produce a general index.

PCA is a technique to reduce data dimensionality from a set of correlated variables to a set of uncorrelated principal components by weighting linear combinations of the original variables for each component. This is a way to produce a simple index for food security, by reducing a large data set to a single indicator.

This mathematical technique aims to determine the weights for variables that share the effect for a particular item. The principal component weight vector, $\boldsymbol{w_j} = (w_{j1}, w_{j2}, \dots, w_{ji})'$ which use linear composite to maximize the variation $Var(Y_j)$ from the original variables $\boldsymbol{x} = (x_{j1}, x_{j2}, \dots, x_{ji})'$ where $Y_j = \boldsymbol{w_j}'\boldsymbol{x}$ (Movellan, 1997).

$$Var(Y_j) = \frac{1}{n}\sum_i (\boldsymbol{x}.\boldsymbol{w})^2$$

$$= \frac{1}{n}(\boldsymbol{x}.\boldsymbol{w})^T(\boldsymbol{x}.\boldsymbol{w})$$

$$= \frac{1}{n}\boldsymbol{w}^T.\boldsymbol{x}^T.\boldsymbol{x}.\boldsymbol{w}$$

$$= \boldsymbol{w}^T.\frac{\boldsymbol{x}^T.\boldsymbol{x}}{n}.\boldsymbol{w}$$

$$= \boldsymbol{w}^T.\boldsymbol{v}.\boldsymbol{w} \tag{1.1}$$

where the maximum $\sum_i w_{ji}\, x_i$ is limited to $\sum_j w_{ji}^2 = \left\|\boldsymbol{w_j}\right\|^2 = 1$ (1.2)

The weight sizes are constrained in Equation 1.2 to avoid the large variance of the linear composite by selecting large weights (Dunteman, 1989; Keho, 2012).

$$\boldsymbol{\mathcal{L}}(\boldsymbol{w}, \lambda) = Var(Y_j) - \lambda(\boldsymbol{w}^T\boldsymbol{w} - 1) \tag{1.3}$$

$$\frac{\partial L}{\partial \lambda} = \boldsymbol{w}^T\boldsymbol{w} - 1 \tag{1.4}$$

$$\frac{\partial L}{\partial \boldsymbol{w}} = 2\boldsymbol{v}\boldsymbol{w} - 2\lambda\boldsymbol{w} \tag{1.5}$$

By setting the derivative equations equal to zero at optimum maximization point,

$$\boldsymbol{w}^T\boldsymbol{w} = 1 \tag{1.6}$$

$$\boldsymbol{v}\boldsymbol{w} = 2\lambda\boldsymbol{w} \tag{1.7}$$

Solving these equations for $\boldsymbol{w}$ will give a principal component that maximizes the variation subject the restriction for the loading of variables, and determines the scores for the principal components vector by the function

$$Y_j = \sum_i w_{ji}\, x_i$$

$$or\ Y_j = (w_{j1}\bullet x_1) + (wj_2\bullet x_2) + \ldots + (w_{ji}\bullet x_i) = \boldsymbol{w_j}'\boldsymbol{x}, \tag{1.8}$$

Where Yj is one component score for a component factor, for j = 1, 2, .., J.

w_{ji} is principal component loading (weighting) for original value (Yu et al.), for i = 1, 2, .., I.

$$\sum_j w_{1i} w_{2i} = \boldsymbol{w_2}' \boldsymbol{w_1} = 0 \qquad (1.9)$$

Also, the linear independence of loading for each two components is the other constraint of PCA when there are more than one component, which means that each two principal components are linearly independent (Dunteman, 1989). Equation 1.9 shows that component 1 is linearly independent of component 2.

1.3.2 Food Security Indicators at the National Level

Using data on a national level is a way to give a more general picture of food security in any country even if the household level is more accurate to measure the effect of factors that impact food security such as income, age, education, or family type for each household. The advantage of using the measure on the national level is that researchers could compare performance and progress of government programs on food security over time and evaluate which program needs to improve while using measures on the household level is better to find the most significant factors of household characterizations on food security.

In this study, four pillars of food security (availability, access, utilization, and stability) are considered, assuming that every pillar has different indicators. These indicators for each dimension of food security overlap to make index to one dimension by PC analysis (Figure 1.1).

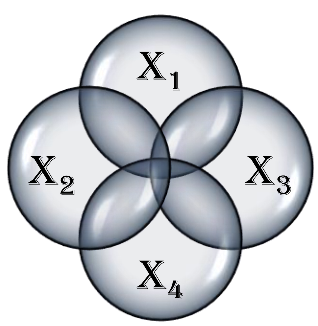

Figure 1.1. Overlap of Indicators of Food Security in each Dimension.

Analysis of the four pillars of food security separately will produce four indexes. So, if the dependent variable values (FS_i) are the four dimensions of food security,

$$FS_{Avaliablity} = (w_{11} \bullet x_1) + (w_{12} \bullet x_2) + \dots + (w_{1a} \bullet x_a), \text{for a} = 1, 2, .., A, \quad (1.10)$$

$$FS_{Access} = (w_{21} \bullet x_1) + (w_{22} \bullet x_2) + \dots + (w_{2b} \bullet x_b), \text{for b} = 1, 2, .., B,$$

$$FS_{Utlization} = (w_{31} \bullet x_1) + (w_{32} \bullet x_2) + \dots + (w_{3c} \bullet x_c), \text{for c} = 1, 2, .., C,$$

and

$$FS_{Stability} = (w_{41} \bullet x_1) + (w_{42} \bullet x_2) + \dots + (w_{4d} \bullet x_d), \text{for d} = 1, 2, .., D.$$

Where (FS_i) is principal component to determine the overall variance for every food security pillar as large as possible with a constraint condition. Each pillar determines through multiple different variables (a, b, c, and d). Also, every pillar may contain one or more than one component.

For each pillar of food security with more than one component, the score of that pillar is the sum of the products of the variables with their loading in every component and use ratio of variance explained by component to total variance explained by all components as the weight for every component factor (Krishnan, 2010). Thus, the model will include the loading for all variables in every component.

$$FS_i = \sum \{(V_k/TV) [(w_{j1} \bullet x_1) + (w_{j2} \bullet x_2) + \dots + (w_{ji} \bullet x_i)]\} \quad (1.11)$$

Where V_k is variance explained by a component k where k = 1, 2, .., K

TV is total variance explained by all components in PCA.

Additionally, this study assumes equal weights for each dimension of food security (Conforti, 2013) to reflect the equal importance of each aspect of food security as expressed with the following equation (1.12).

$$\textit{Food Security Score} = 0.25\ (\textit{Food Availability}) + 0.25\ (\textit{Food Accessibility}) + 0.25\ (\textit{Food Utilization}) + 0.25\ (\textit{Food Stability}) \tag{1.12}$$

1.3.3 Robustness Test

$$\overline{R_s} = \frac{1}{N}\sum_{c=1}^{N}\left|Rank_{ref}(C) - Rank\ (C)\right| \tag{1.13}$$

The equation measures the average shift of rankings for different scenarios of weight (robustness) to aggregate the multiple dimensions of food security (Hudrliková, 2013). The weight for each food security pillar changes with different scenarios as given in next table 1.1. I calculate the robustness of ranks ($\overline{R_s}$) for all countries (N) in this study, which is the absolute difference in country ranks from the rank reference by the use median as reference of rank. The smaller value for each scenario in the robustness equation means more robustness and the scenario has a ranking close to the median ranking. I will evaluate that later after I identify and weight the indicators of food security (Table 1.16).

Table 1.1. Scenarios with different Weight to Chick the Robustness of Aggregation Food Security Pillars.

	Availability	Access	Utility	Stability
Equal Weight	0.25	0.25	0.25	0.25
Alternative 1	0.4	0.1	0.25	0.25
Alternative 2	0.25	0.25	0.1	0.4
Alternative 3	0.25	0.1	0.4	0.25
Alternative 4	0.25	0.4	0.1	0.25
Alternative 5	0.1	0.4	0.25	0.25
Alternative 6	0.25	0.25	0.4	0.1

1.4 Operationalization of Food Security Indicators

The following section presents the construction of indicators that have been used to produce a food security index in previous studies. The distribution of these indicators within the four key dimensions of food security is mentioned by the Food and Agriculture Organization of the United Nations in the annual Statistical Yearbook and annual report of the State of Food Insecurity in the World (FAO, 1990–2015: 2013).

1.4.1 Availability Dimension

- *Average dietary energy supply adequacy* (FAO, 1990–2015: 2013) is determined by the ratio of dietary energy supply in a country to the average dietary requirement of energy measured in calories. The FAO statistic is based on a rolling three-year average. Dietary energy supply includes both food consumed and food wasted.
- *Average value of food production* (FAO, 1990–2015: 2013) is defined as the annual value of food production in the country per capita in dollars. This indicator represents the importance of the agricultural sector in a country and the contribution of this sector to increased food security for any country, depending on its production with some exceptions, such as in countries that have water scarcity. This value is calculated on the average of three years.
- *Share of dietary energy supply derived from cereals, roots and tubers* (FAO, 1990–2015: 2013) is indicated by the rate of energy supply from cereals, roots, and tubers to total dietary energy supply in calories per capita. Research targets these food groups because they play important roles in the provision of food. Also, these food categories are primary sources of carbohydrates, and they also provide some minerals, essential vitamins, and

protein (Diop and Calverley, 1998). This indicator is calculated as an average across three years by the FAO.

- *Average protein supply* (FAO, 1990–2015: 2013) is expressed as the average of national protein supply from different resources per capita each day, measured in grams. Protein supply is important for human nutrition and it comes from different sources including, crops livestock products, and meat. To reduce the impact of possible errors in estimates, this indicator is based on a three-year average .
- *Average supply of protein of animal origin* (FAO, 1990–2015: 2013) is defined as the average of the national daily protein supply from animal resources per capita, measured in grams. In general, the biological value for proteins from animal sources is higher than that of proteins from plant sources. This reflects the importance of animal protein to food security. This indicator includes protein from different groups of animal products, including meat, animal fats, milk, eggs, fish, and seafood products.

1.4.2 Access Dimension

- *Ratio of paved roads to total roads* (FAO, 1990–2015: 2013) reflects the quality of roads by expressing paved roads as a percentage of total roads. The importance of this indicator is that it provides information about the status of physical access to markets. Paved roads reduce the odds of post-harvest losses for producers, and encourage the development of food markets in the country. Also, increases in paved roads may cut the costs of final products, leading to the enhancement of food security.
- *Road density* (FAO, 1990–2015: 2013) is expressed as kilometers of road per 100 square km of land area across countries. The road in general, paved or non-paved, is important for trade and makes physical access to food easier.

- *Rail line density* (FAO, 1990–2015: 2013) is the total railroad route in kilometers per 100 square km of land area across countries. Increase rail line density contributes to the easy physical access of food.
- *Domestic food price index* (FAO, 1990–2015: 2013) is an indicator of the relative price of food in a country. This index is calculated by dividing both food and non-alcoholic beverage expenditures by actual individual consumption. This value is calculated in purchasing power parity terms relative to the United States. Agriculture and energy policy, market speculation, unexpected weather, changes in global demand, and surplus stock are factors that influence food price volatility (Johnson, 2011). The relationship between prices and food security is obvious. The crisis of food prices between 2007 and 2008 led to increases in the number of food–insecure people in 70 developing countries by nearly 11 percent, or by about 80 million people (Shapouri, 2010).
- *Prevalence of undernourishment* (FAO, 1990–2015: 2013) reflects the sufficiency of calorie intake by determining the percentage of undernourished people in a given population, and it represents the probability of a randomly selected individual's consuming an insufficient amount of calories required for an active and healthy life. This indicator is computed at an average of individual level by taking the rate of habitual daily dietary energy consumption to a threshold level called the minimum dietary energy requirement. The prevalence of undernourishment is a traditional indicator in FAO statistics for food security (FAO statistics, 2014).
- *Gross domestic product per capita* (in purchasing power equivalent) (EIU, 2015; FAO, 1990–2015).

- *Share of food expenditure of the poor* (FAO, 1990–2015: 2013) is the ratio of food consumption for the lowest income group (poor people) to the total consumption of an area.
- *Depth of the food deficit* (FAO, 1990–2015: 2013) is calculated as the amount of calories needed to eliminate the undernourishment level in the country. It is the difference between the average of calorie requirement and the current average number of calories consumed by undernourished people (World Bank, 2015).
- *Prevalence of food inadequacy* (FAO, 1990–2015: 2013) measures dietary energy requirements in calories relative to physical activity levels (normal or intense) for the population in a given country.

1.4.3 Utilization Dimension

- *Access to improved water sources* (FAO, 1990–2015: 2013) is the percentage of the total population using an improved drinking water source in the country (World Bank, 2015). This indicator provides information that is useful to assess the utilization dimension of food security outcomes. The importance of this indicator is derived by water being a key element for food security, including water required for drinking, sanitation, and food production.
- *Access to improved sanitation facilities* (FAO, 1990–2015: 2013) is the percentage of the total population using improved sanitation facilities in the country (World Bank, 2015). This indicator is useful to assess the utilization dimension of food security outcomes and it expresses access to safe water. The relationship between food security and the availability of sanitation facilities appears when there is a lack of sanitation facilities, which increases diarrheal disease, reducing the benefit of food nutrition.

- *Percentage of children under 5 years of age affected by wasting* (FAO, 1990–2015: 2013) is the proportion of children between 0 and 5 years of age whose weight relative to height is more than two standard deviations below the median for the international reference population. This indicator measures wasting prevalence (WHO, 2000–2014).
- *Percentage of children under 5 years of age who are stunted* (FAO, 1990–2015: 2013) is the proportion of children aged 0 to 5 years whose height is more than two standard deviations below the median for the international reference population (WHO, 2000–2014).
- *Percentage of children under 5 years of age who are underweight* (FAO, 1990–2015: 2013) is the proportion of children ranging in age from new born to five years of age whose weight-for-age is below the standard by two to four kg for his or her age group.
- *Prevalence of anemia among pregnant women* (FAO, 1990–2015: 2013) is the proportion of pregnant women whom have anemia, as indicated by levels of hemoglobin in the blood below 110 grams per liter, at sea level (World Bank, 2015).
- *Prevalence of anemia among children under 5 years of age* (FAO, 1990–2015: 2013) is the proportion of children ranging in age from new born to five years who have anemia, as indicated by hemoglobin levels below the standard for his or her age.
- *Prevalence of vitamin A deficiency in the population* (FAO, 1990–2015: 2013) is the proportion of a population with a lack of vitamin A intak to the total population.
- *Prevalence of iodine deficiency* (FAO, 1990–2015: 2013) is the percentage of the population having an iodine rate below the standard relative to the total population.

1.4.4 Stability Dimension

- *Cereal import dependency ratio* (FAO, 1990–2015: 2013) refers to the dependency of a country on imports meet the demand for domestic cereal consumption. This measure indicates the percentage of dependency on a domestic food supply rather than imported food. Values approaching 100 indicate that the country depends on imported food for consumption. Conversely, increases in dependence on the domestic production of food will reduce this ratio (Napoli, 2011). The cereal import dependency (CIDR) ratio is calculated as

$$CIDR = \frac{Imports}{Production + Imports - Exports} * 100. \tag{1.14}$$

- *Percent of arable land equipped for irrigation* (FAO, 1990–2015: 2013) is other important indicator of food security because increased domestic food production results in higher levels of stability in food supplies. Increases in the percent of arable land equipped for irrigation contribute to the growth of domestic production, and protect the food supply from the external effects of other countries.
- *Value of food imports over total merchandise exports* (FAO, 1990–2015: 2013) measures the proportion of the value of food imports to the total value of merchandise exports. Increases in this proportion mean that there is more dependence on exports to finance food meaning that the country depends on other countries to get food.
- *Political stability and absence of violence/terrorism* (EIU, 2015; FAO, 1990–2015: 2013) reflects the likelihood of unexpected changes in government that can lead to changes in government programs and the likelihood of violence. Government instability and violence increase the risks involved with food investment.

Table 1.2. Summary of Food Security Indicators and the Data Sources.

Indicator	Resource	Indicator	Resource
Availability		**Utilization**	
1- Average dietary energy supply adequacy	FAO	1- Access to improved water sources	FAO
2- Average value of food production	FAO	2- Access to improved sanitation facilities	FAO
3- Share of dietary energy supply derived from cereals, roots, and tubers	FAO	3- Percentage of children under 5 years of age affected by wasting	FAO / WHO / UNICEF
4- Average protein supply	FAO	4- Percentage of children under 5 years of age who are stunted	FAO / WHO / UNICEF
5- Average supply of protein of animal origin	FAO	5- Percentage of children under 5 years of age who are underweight	FAO / WHO / UNICEF
		6- Percentage of adults who are underweight	FAO / WHO
Access		7- Prevalence of anemia among pregnant women	FAO
1- Percent of paved roads over total roads	FAO	8- Prevalence of anemia among children under 5 years of age	FAO
2- Road density	FAO / WB	9- Prevalence of vitamin A deficiency in the population	FAO
3- Rail lines density	FAO	10- Prevalence of iodine deficiency	FAO
4- Gross domestic product per capita	FAO		
5- Domestic food price index	FAO / WB	**Stability**	
6- Prevalence of undernourishment	FAO / WB	1- Cereal import dependency ratio	FAO
7- Share of food expenditure of the poor	FAO	2- Percent of arable land equipped for irrigation	FAO
8- Depth of the food deficit	FAO	3- Value of food imports over total merchandise exports	FAO / UNCTAD
9- Prevalence of food inadequacy	FAO	4- Political stability and absence of violence/terrorism	FAO / WB
		5- Domestic food price volatility	FAO
		6- Per capita food production variability	FAO
		7- Per capita food supply variability	FAO

- *Domestic food price volatility* (FAO, 1990–2015: 2013). High levels of volatility in food prices, make it difficult for poor families to manage their income to meet food needs.
- *Per capita food production variability* (FAO, 1990–2015: 2013) represents the effect of changes in food production on the food supply of the population (EIU, 2015).

- *Per capita food supply variability* (FAO, 1990–2015: 2013) reflects variations in food supply (production and import) that affect the quantity for a population. Poor people are most affected because they cannot meet increases in the prices that result from increased competition for limited food.

1.5 Geographical Focus of the Study

This study focuses on several different high-, middle-, and low-income countries. The following criteria determined the inclusion of each country for consideration in the study: (a) the availability of information for the country, and (b) the political stability within the country in the period of study. Consistent information availability and political stability across the sample helped to ensure fair comparisons among the countries. The countries that met the selection criteria are 59 countries distributed between developed and developing countries, and different parts of the world as following:

Africa: Algeria, Ethiopia, Morocco, Senegal, South Africa, and Tunisia.

Asia: India, Indonesia, Iran, Japan, Jordan, Kuwait, Laos, Malaysia, Oman, Pakistan, Republic of Korea, and Saudi Arabia.

North America: Canada, Mexico, and the United States.

South America: Brazil, Chile, Colombia, Costa Rica, El Salvador, Nicaragua, Paraguay, and Peru.

Europe: Austria, Belarus, Belgium, Bolivia, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Netherland, Norway, Poland, Portugal, Republic of Moldova, Russian Federation, Slovakia, Spain, Sweden, Switzerland, Turkey, Ukraine, and United Kingdom.

1.6 Principal Component Analysis Procedure

1.6.1 Data Resources

The primary data resource for this study is FAO statistics (FAO, 2016). There is a large amount of missing data for the study period (2000 to 2011); for example, for countries under a 5 percent level of undernourishment no specific information the prevalence of undernourishment is provided. As such, the study depends on additional resources, such as the De Agostini Geografia website (http://www.deawing.com/), which can be used to calculate the data missing from percent of paved roads over total road network, and road density indicators in different countries. Also, the website of General Directorate of Highways in the Republic of Turkey (http://www.kgm.gov.tr/) is the reference for the percent of paved road, and road density. Additionally, this research uses the International Food Policy Research Institute (IFPRI) dataset in the Global Hunger Index (GHI) report for the period of 2006 through 2014 as another resource for prevalence of undernourishment, and percentage of children under 5 years of age who are stunted, wasting, and underweight indicators (Von Grebmer et al., 2014). Finally, another resource for indicators of the percentage of children under 5 years of age who are stunted, wasting, and underweight is World Health Statistics (2000–2014) from the World Health Organization (WHO, 2000–2014).

1.6.2 Missing Data

After combining different references for data, there were still there some indicators that had missing data. So, I looked for other ways to close the gaps in the data. The options for dealing with missing data include deleting or imputing variables with missing data. Usually, a variable is omitted if the variable that has missing data represents less than 5 percent of the total data (Joint Research Centre-European Commission, 2008; Lomax and Schumacker, 2010). On the other hand, the data imputation could be a single imputation that gives one value for missing data, or multiple imputations that provide several values for each missing value. Substitution using mean, median, or mode, regression imputation, and expectation-maximization imputation are examples of single imputation. The Markov Chain Monte Carlo algorithm is an example of multiple imputations.

Following the advice of Lomax and Schumacker (2010), I use an unconditional mean imputation to fill in missing data points, which is what they recommend if the size of the dataset with missing values is small. The equation for the sample mean is

$$\overline{x_{q,c}} = \frac{\sum x_{q,c}}{m_{q,c}}, \tag{1.15}$$

where

$x_{q,c}$ is the observed value of random variables for individual indicator (Hackett et al., 2008) in a country (c),

$m_{q,c}$ is the number of available values in a country (c) for specific indicator (Hackett et al., 2008), and

$\overline{x_{q,c}}$ is the average value of indicator (Hackett et al., 2008) for one country (c).

The potential problem of using the sample mean method is that imputed values could produce biased estimates of the population mean (Joint Research Centre-European Commission, 2008).

1.6.3 Normalization the Indicators

Before using PCA, the data need to be subjected to mathematical transformation in order to create an aggregated index on a standard scale. Several techniques are appropriate for standardizing scores for variables that are measured on different scales (Freudenberg, 2003; Joint

Research Centre-European Commission, 2008; Saisana and Tarantola, 2002). The following list provides examples of methods used to create uniform scale values:.

1. Ranking countries' performance on every variable is simplest method of scaling data.
2. Standardization, or computing z-scores, is a common method to standardize the measure to a zero mean and standard deviation equal to one, as expressed in the following equation.

$$z - score = \frac{actual\ value – mean}{standard\ deviation} \tag{1.16}$$

3. The Min-Max technique references the distance between the best and worst performance. This transformation method is used for variables that range between zero and one. The equation is used for this method is

$$\frac{actual\ value - Min\ value}{Max\ value - Min\ value}$$

4. Distance from reference country is a method of standardization that assumes that the leader country and the values of all other countries are distributed around the value of reference country, where some countries are below the reference value and others are above it.

$$\frac{actual\ value}{value\ of\ reference\ country}$$

5. Distance from mean value is simply dividing the actual value by the mean value, where the distance from mean decides the score for each country.

$$\frac{actual\ value}{mean\ value}$$

6. Categorical scales assign a sequence number to every variable and the score depends on percentiles of actual values of the variables across countries.

The standardized or (z-score) technique was used for every indicator across countries during the period studied (2000–2011). In addition to the indicators that are shown in the final results of the PCA, the standardization of data was completed on all 31 variables that are represented by FAO data as indicators of food security across all countries in world (226 countries) during the period of 1990 to 2011.

It was assumed, as in most previous studies, that the food security level in any country is the sum of several indicators that were classified into four dimensions (availability, access, utilization, and stability). STATA statistical programming was used to build the code that conducts the PCA on the average available data from the FAO dataset from 1990 to 2011, for all 31 indicators across all countries (FAO 1990–2015). The PCA provides a separate investigation for every pillar of the four food security pillars. The number of valid data for each dimension is determined automatically after running the analysis, and the program excludes any countries that have missing data for one of indicators that is included in the dimension under analysis.

1.7 Results

1.7.1 Availability Dimension

The 5 indicators that determine this dimension according the State of Food Insecurity annual report are listed below (FAO, 2013), and all of them showed a significant effect on this dimension:

1. Average dietary energy supply adequacy.
2. Average value of food production.
3. Share of dietary energy supply derived from cereals, roots, and tubers.
4. Average protein supply.

5. Average supply of protein of animal origin.

The correlation matrix for the variables in this dimension show high correlations for most variables. Average protein supply and average supply of protein of animal origin have relatively higher positive correlations, while average supply of protein of animal origin and the share of dietary energy supply derived from cereals, roots, and tubers have higher negative correlation.

Table 1.3. Correlation Matrix of Availability Dimension.

	Energy_Supply	VF_Prpduction	Energy_Supply_CRT	Protein_supply	animal_protein
Energy_Supply	1.000				
VF_Prpduction	.465	1.000			
Energy_Supply_CRT	-.591	-.567	1.000		
Protein_supply	.841	.547	-.715	1.000	
animal_protein	.697	.595	-.860	.909	1.000

Table 1.4. Total Variance Explained in the Availability Dimension.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.74	74.08	74.08	3.74	74.08	74.08
2	.605	12.11	86.91			
3	.435	8.70	95.61			
4	.184	3.69	99.30			
5	.035	.70	100.000			

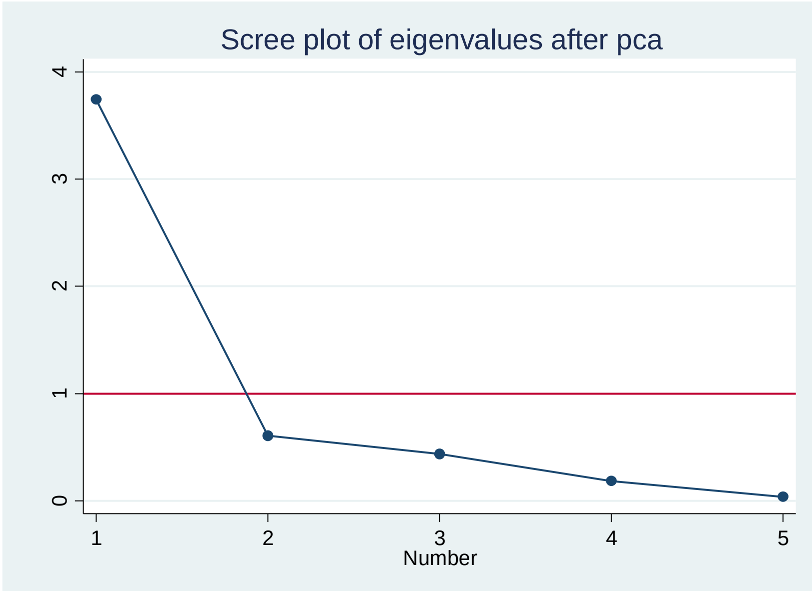

Figure 1.2. Scree Plot for the Availability Dimension.

Table 1.5. Component Matrix for the Availability Dimension.

Variables	**1st Component**	**Unexplained**
Average dietary energy supply adequacy	.433	.3
Average value of food production	.366	.5
Share of dietary energy supply derived from cereals, roots, and tubers	-.449	.25
Average protein supply	.484	.12
Average supply of protein of animal origin	.491	.1
Eigenvalue	3.74	-
Percent variance	74.08	-
Cumulative Variance	74.08	-
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.69	
Size of Data (N)	163	

PCA output also includes a table of total variance explained, which lists the eigenvalues for each linear component. According to Table 1.4, the first component explains 74% of the total variance. The program extracts all eigenvalues larger than 1, and there is only one component factor. The scree plot in Figure 1.2 confirms that a single component explains most of the variance on this dimension, in that one point rests before the elbow of curve, then the curve plateaus.

The column Unexplained in table 1.5 reflects the percent of variance that is not explained by the extract component and that could be explained by other components. Some of variances in the variables are unexplained by one component but these values are acceptable if they are not larger than 0.7 (Field, 2009). A total of 163 countries had available data for all of these indicators. The Kaiser-Meyer-Olkin (KMO) and Bartlett’s test of sphericity are important parts of the PCA output. These tests measure sampling adequacy. KMO measures range from 0 to 1. Values approaching 1 indicate that the correlation patterns are compact and factor analysis results are reliable. KMO values approaching 0 indicate that variables are inappropriate for creating an index. The analysis is acceptable when the value of the KMO test is equal to or larger than 0.5 (Kaiser, 1974). If the PCA output shows that the KMO value is less than 0.5, more data is needed, or different variables may need to be included. Table 1.5 shows the results of KMO and Bartlett's tests for the five indicators for the availability dimension. The value of the KMO measure of sampling adequacy is 0.69, which is acceptable. This test indicates that the principal component model is appropriate for the availability dimension.

Also, Table 1.5 shows the loading of each variable in on the single component extracted by the PCA. The loading values in the component matrix are helpful in determining the final value of the component. A positive value for weighting or loading for the availability dimension represents average dietary energy supply adequacy, average value of food production, average protein supply, and average supply of protein of animal origin. A negative value appears for the share of dietary energy supply derived from cereals, roots, and tubers.

1.7.2 Access Dimension

Nine indicator variables are included in this dimension, following the State of Food Insecurity annual report (FAO, 2013). These variables are separated into subgroups according to the same report. The subcategories represent physical and economic access in static and dynamic determinants of indicators. Also, there are other components in the outcomes that contain some of variables that load on the accessibility dimension. To decide of whether or not the dimension contains subgroups, an analysis of all indicators on this dimension is necessary. Accessibility indicators include the following:

1- Percent of paved roads over total roads.

2- Road density.

3- Rail line density.

4- Gross domestic product per capita.

5- Domestic food price index.

6- Prevalence of undernourishment.

7- Share of food expenditure of the poor.

8- Depth of the food deficit.

9- Prevalence of food inadequacy.

Tables 1.6 through 1.8 and Figure 1.3 present results of the PCA for the access dimension of food security. The sample size for this data set is 94 countries out of a total of 226 countries that were available for this analysis (Table 1.8); the PCA exclude any country that has missing data for one variable, as mentioned before. Also, the results indicate that only 5 of the original 9 variables were valid for the analysis because of less availability of data for the remaining 4 variables across countries. Percent of paved roads over total roads, road density, rail line density, gross domestic product per capita, and domestic food price index best represented the dimension of food access given the available data.

Table 1.6 indicates that the correlation between different variables is moderate to strong correlation in general. The positive strong correlations are between percent of paved road to total road with rail line density, road density with rail line density, as well as GDP per capita with percent of paved road to total road, road density, and rail line density. The negative correlation appears between domestic food price index with all other variables (percent of paved roads over total roads, road density, rail line density, and gross domestic product) as expected.

Table 1.6. Correlation Matrix of Access Dimension.

	Paved_road	Road_density	Rail_lines	GDP	Food Price Ind.
Paved_road	1.000				
Road_density	.467	1.000			
Rail_lines	.617	.813	1.000		
GDP per capita	.537	.554	.579	1.000	
Food Price Index	-.469	-.442	-.488	-.757	1.000

Table 1.7 represents the total variance explained by all components and by the extracted component. Values represent the amount of variance or eigenvalue in the original variables that is accounted for by each component of the total of initial eigenvalue column. There are five components, and PCA extracted components with eigenvalues greater than 1. Only one

component extracted represent 66% of the cumulative variance accounted for by the 5 components. Scree plot show 5 dots represent the component factors (Figure 1.3). This scree plot suggests a natural break between the first component with high eigenvalue and the other components with low eigenvalues, which further supports the results from table 1.7.

Table 1.7. Total Variance Explained for the Accessibility Dimension.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.30	65.95	65.95	3.30	65.95	65.95
2	0.77	15.31	81.27			
3	0.54	10.85	92.12			
4	0.23	4.64	96.76			
5	0.16	3.24	100			

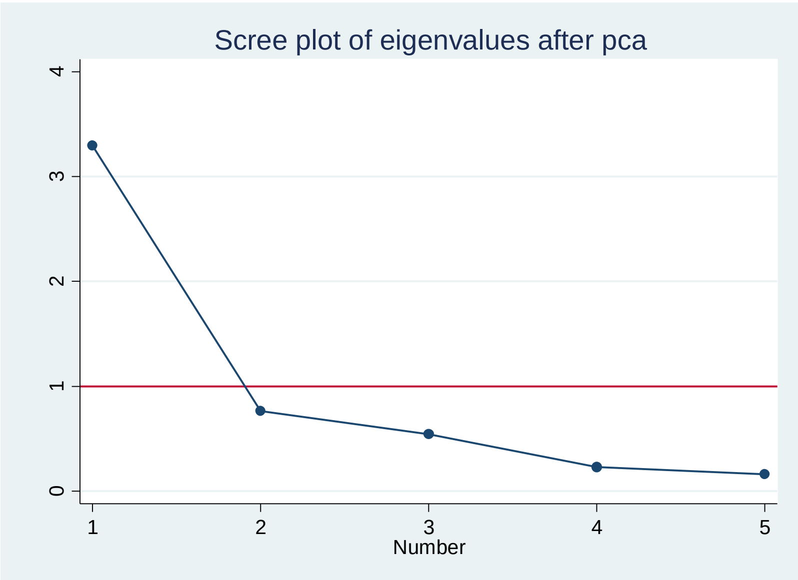

Figure 1.3. Scree Plot of the Accessibility Dimension.

Table 1.8. Component Matrix for the Accessibility Dimension.

Variables	**1st Component**	**Unexplained**
Percent of paved roads over total roads	.415	.43
Road density	.448	.33
Rail lines density	.478	.25
Gross domestic product per capita	.466	.28
Domestic food price level index	-.426	.40
Eigenvalue	3.29	-
Percent variance	65.95	-
Cumulative Variance	65.95	-
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.75	
Size of Data (N)	94	

Table 1.8 displays an acceptable result for the measurement of sampling adequacy, KMO = 0.75, which is above the borderline of acceptability (Kaiser, 1974). Table 1.8 also shows the proportions of variance unexplained by variables that were included in the analysis for the food accessibility dimension, which all of them are below 0.70. The most of variance for the rail line density indicator is explained by the extractor component which only 25 percent of variance does not explain by first component. The percent of paved roads over total roads indicator has a smaller shared variance value. In addition, table 8 shows the loading of variables for the accessibility dimension. The component score is computed by multiplying the standardized values of all variables in the dimension by the component's score coefficients. The resulting one component score variables are representative of the 5 original variables. Percent of paved roads over total roads, road density, rail lines density, and gross domestic product per capita have a

positive correlation with first component, while domestic food price index has a negative correlate.

1.7.3 Utilization Dimension

Ten variables indicate this dimension, according to the State of Food Insecurity annual report (FAO, 2013). Also, these variables are separated into subgroups according to the same report. Some indicators represent static and dynamic determinants of food security, and other variables appear as food security factors for the utility dimension. All of the indicator variables for this dimension need to be analyzed in order to determine which to include. The indicators for the utilization dimension of food security are:

1. Percentage of population with access to improved water sources.
2. Percentage of population with access to improved sanitation facilities.
3. Percentage of children under 5 years of age affected by wasting.
4. Percentage of children under 5 years of age who are stunted.
5. Percentage of children under 5 years of age who are underweight.
6. Percentage of adults who are underweight.
7. Prevalence of anemia among pregnant women.
8. Prevalence of anemia among children under 5 years of age.
9. Prevalence of vitamin A deficiency in the population.
10. Prevalence of iodine deficiency.

The investigation of all ten variables in utilization dimension using PCA defines four variables that work the best for the analysis, including percentage of population with access to improved water sources, percentage of population with access to improved sanitation facilities, prevalence of anemia among pregnant women, and prevalence of anemia among children under 5 years of age. The other variables were excluded for reason of uncompleted data for all countries during the study period. The average values for the period between 1990 and 2011 for these variables are visible for 182 countries of the 227 countries in the database (Table 1.11). The correlation matrix displays high to moderate correlations among the four indicators for the utilization dimension (Table 1.9). The prevalence of anemia among pregnant women and children under 5 years are positive correlated. On the other side, the access to improved water sources and sanitation facilities decrease the anemia for pregnant women and children.

Table 1.10 displays the total amount of variance that is explained by each factor of the component; only one value is greater than 1.0 (=3.39). The scree plot confirms the resulting single component for this dimension of food security, in that most of eigenvalue was explained by one component (Figure 1.4).

Table 1.9. Correlation Matrix of Utilization Dimension.

	water_sources	sanitation_facilities	anemia among pregnant	anemia among children
water_sources	1.000			
sanitation_facilities	.829	1.000		
anemia among pregnant	-.668	-.783	1.000	
anemia among children	-.749	-.842	.918	1.000

Table 1.10. Total Variance Explained for the Utilization Dimension.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.397	84.94	84.94	3.397	84.94	84.94
2	.385	9.64	94.57			
3	.145	3.62	98.19			
4	.072	1.18	100.000			

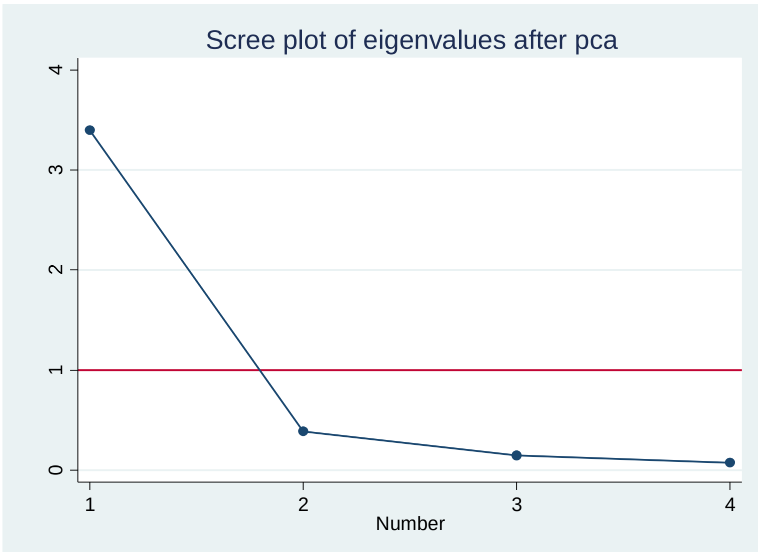

Figure 1.4. Scree Plot for the Utilization Dimension.

The measure of the sampling adequacy for the utilization dimension yielded higher values compared with all of the other three dimensions (availability, accessibility, and stability). KMO = 0.78 (Table 1.11), which means that the pattern of correlation between variables is relatively compact, indicating that PCA is useful and appropriate. Also table 1.11 shows the loading of every indicator for the utilization dimension of food security on the component. There were positive correlations for two variables including prevalence of anemia among pregnant women, and prevalence of anemia among children under 5 years of age. Negative correlations resulted for percentage of population with access to improved water sources, and percentage of population with access to improved sanitation facilities. That means the percentage of population with access to improved water sources and improved sanitation facilities variables have opposite effect of other two variables (prevalence of anemia among pregnant women, and children under 5 years of age), while the signs do not reflect the direct effect toward utilization dimension.

Table 1.11. Component Matrix for the Utilization Dimension.

Variables	**1st Component**	**Unexplained**
Percentage of population with access to improved water sources	-.476	.23
Percentage of population with access to improved sanitation facilities	-.509	.12
Prevalence of anemia among pregnant women	.497	.16
Prevalence of anemia among children under 5 years of age	.518	.1
Eigenvalue	3.39	-
Percent variance	84.94	-
Cumulative Variance	84.94	-
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.784	
Size of Data (N)	182	

1.7.4 Stability Dimension

Seven variables or indicators represent this dimension, as published in the State of Food Insecurity annual report (FAO, 2013). These variables are separated into two subgroups according to the same report. Some indicators represent vulnerability of stability, and others represent shock of stability. PCA was used to identify the variables to include as a reference for the stability dimension. This analysis also helps to determine whether or not this dimension contains subgroups. All indicators are assumed to participate in this dimension of food security, and the output of the analysis determines the choices. The variables involved in this analysis are:

1. Cereal import dependency ratio.
2. Percent of arable land equipped for irrigation.
3. Value of food imports over total merchandise exports.
4. Political stability and absence of violence/terrorism.
5. Domestic food price volatility.
6. Per capita food production variability.
7. Per capita food supply variability.

The analysis identified 152 countries available with five indicators for the stability dimension of food security including cereal import dependency ratio, value of food imports over total merchandise exports, per capita food production variability, and per capita food supply variability. The correlation matrix of the four indicators that were chosen (Table 1.12) shows small correlations among the variables. All of the absolute values were less than 0.4. Otherwise, the total amount of variance in the original variables is explained by every component. Table 1.13 shows two components that have values greater than 1, which represent 66% of the variance accounted by all four components. So, the extracted factors are these two components. The scree plot of the eigenvalues for each component in the initial solution also confirmed that the two components explained most of variance for the four variables. The two primary components show a steep or relatively steep slope, and the third and fourth components contribute little to the solution (Figure 1.5).

Table 1.12. Correlation Matrix for the Stability Dimension.

	Cereal import dependency ratio	Food imports over total merchandise exports	Food production variability	Food supply variability
Cereal import dependency ratio	1.000			
Food imports over total merchandise exports	.246	1.000		
Food production variability	-.382	-.138	1.000	
Food supply variability	-.105	.007	.228	1.000

Table 1.13. Total Variance Explained for the Stability Dimension.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.44	35.99	35.99	1.44	35.99	39.91
2	1.19	29.88	65.87	1.19	29.88	65.87
3	.779	19.47	85.34			
4	.586	14.66	100.000			

In contrast, KMO and Bartlett's test (Table 1.14) yielded acceptable output. The sampling adequacy measure (KMO test) is 0.57, which means that 57.3% of the variance is accounted for by underlying factors of the component. This KMO test value is low, but sufficient to accept (Kaiser, 1974). Table 1.14 also shows variance that is unexplained by each of the original variables composing the components. All variables have variance values that are large enough to justify including them in the analysis.

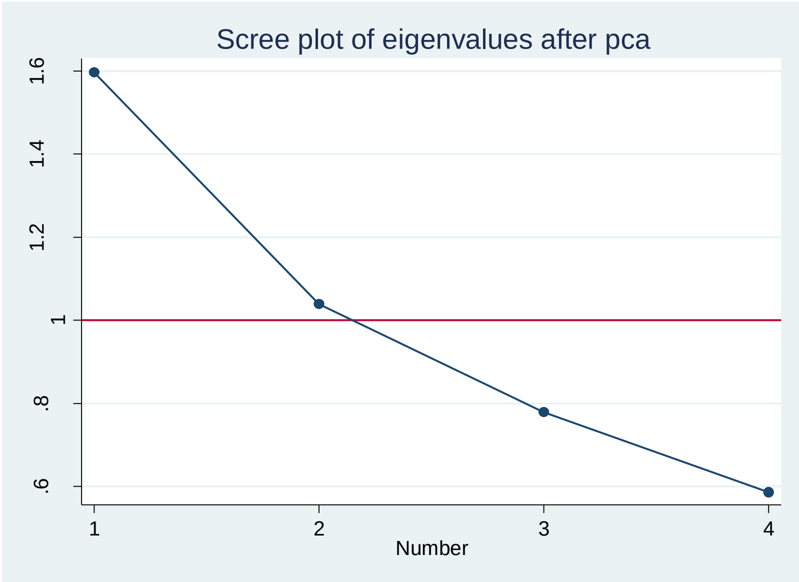

Figure 1.5. Scree Plot for the Stability Dimension.

Table 1.14. Component Matrix for the Stability Dimension.

Variables	**1st Component**	**2nd Component**	**Unexplained**
Cereal import dependency ratio	.614	-.165	.37
Value of food imports over total merchandise exports	.664	.332	.34
Per capita food production variability	-.414	.482	.37
Per capita food supply variability	.102	.794	.27
Eigenvalue	1.439	1.195	-
Percent variance	35.99	29.88	-
Cumulative Variance	35.99	65.87	-
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	.57		
Size of Data (N)	152		

The component matrices (Table 1.14) contain loading values for each variable on the two principal components. The cereal import dependency ratio and value of food imports over total merchandise exports load heavily on the first component, and per capita food production variability loaded most heavily on the second component.

1.7.5 The Result of Robustness Test

Using STATA code, I applied equation 1.7 using several scenarios of weight mentioned in table 1.1 for some countries in this study case such Brazil, Germany, Japan, Jordan, Malaysia, Morocco, Saudi Arabia, Turkey, and the United States during 2000–2011. First, this code ranks these countries for every year using different scenarios of weight. For example, table 1.15 shows the countries ranking in 2005 for seven scenarios of weight for each country in this year. Then, the code applied equation 1.7 to assessing the robustness for each scenario of weight. This equation assesses the robustness by measuring the absolute value of average differences in countries' rankings from their median ranks. The weight scenario with small shift in ranking is the recommended weight for aggregation between different dimensions of food security. Table 1.16 displays the robustness measures between 2000–2011 for 9 countries and 7 scenarios. The average difference of absolute value between equal weight scenario and reference of ranking (median) has small values during all study time period. This indicates that the equal weight scenario is more robust for the time of study compared to other scenarios and it is recommended according to the robustness test to aggregate the four dimensions of food security for the food security index.

Table 1.15. Ranking Different Countries use Several Scenarios of Weight in 2005.

	Eq. Weight	Alter. 1	Alter. 2	Alter. 3	Alter. 4	Alter. 5	Alter. 6
Brazil	36	32	35	35	36	38	36
Germany	6	10	5	10	5	2	7
Japan	23	25	23	23	23	20	22
Jordan	45	46	50	42	47	44	39
Malaysia	35	37	34	36	33	34	35
Morocco	49	49	48	49	49	49	49
Saudi Arabia	42	43	44	43	40	40	41
Turkey	27	24	25	28	27	28	29
United States	2	1	4	1	6	8	2

Table 1.16. Robustness of Different Weights for Food Security Pillars between 2000–2011.

	Eq. Weight	Alter. 1	Alter. 2	Alter. 3	Alter. 4	Alter. 5	Alter. 6
2000	0	0.22	0	0	0.22	0.22	0.22
2001	0	0.22	0	0.22	0.22	0.22	0.22
2002	0	0.22	0.22	0.22	0.22	0.22	0.22
2003	0	0	0	0	0.44	0.44	0.44
2004	0	0	0.22	0	0.44	0.44	0.44
2005	0	0.44	0.22	0.44	0.22	0.22	0.22
2006	0	0.44	0.22	0.44	0.22	0.22	0.22
2007	0	0.44	0.22	0.44	0.22	0.22	0.22
2008	0	0.67	0	0.22	0.44	0.44	0.44
2009	0	0.44	0.67	0.44	0.44	0.44	0.44
2010	0	0.22	0.67	0.44	0.44	0.67	0.44
2011	0	0.22	0.67	0.44	0.44	0.67	0.67

1.7.6 Food Security Index

The food security index was built on different indicators that comprise the four pillars of food security. The PCA of all of the indicators for the four pillars that are included in the FAO dataset (FAO, 1990–2015) suggests that five indicators in one component represent availability, five indicators in one component represent accessibility, four indicators in one component represent utilization, and four indicators in two components represent availability (Table 1.17). In general, all of these pillars, with several indicators loading on different components, represent food security. The overall weighting is found by multiplying PCA loading values with the component weighting, and each dimension with similar weighting (1 out 4) indicates the equal importance of each of the four pillars to the food security index as assuming previously in equation 1.6 and these weights confirm by robustness test result (Table 1.16). The stability dimension is divided into two subgroups as the PCA suggested, and the two subgroups are weighed by the ratio of variance explained by every component to total variance explained from all extracted components as illustrated in equation 1.5.

The indicator values from the analysis have the expected weighting sign relative to their effect on food security. The sign of loading in PCA is arbitrary whereas the variance will not change as the signs of variables are reversed (Harman, 1976). Therefore, the signs for indicators' loading of PCA are reversed for all indicators of utility and stability dimensions, because changes in these variables leads to changes in food security in opposite direction and does not reflect the logical relationship.

Table 1.17. Summary of the Analysis of Indicators Loading on the Food Security Index by PCA.

	Indicator	PCA Loading		Component Weight	Dimension
1	Average dietary energy supply adequacy (x_{11})	.433			
2	Average value of food production (x_{12})	.366			
3	Share of dietary energy supply derived from cereals, roots, and tubers (x_{13})	-.449		.25	Availability
4	Average protein supply (x_{14})	.484			
5	Average supply of protein of animal origin (x_{15})	.491			
6	Percent of paved roads over total roads (x_{21})	.42			
7	Road density (x_{22})	.45			
8	Rail lines density (x_{23})	.48		.25	Accessibility
9	Gross domestic product per capita (x_{24})	.47			
10	Domestic food price level index (x_{25})	-.43			
11	Percentage of population with access to improved water sources (x_{31})	(.476)			
12	Percentage of population with access to improved sanitation facilities (x_{32})	(.509)		.25	Utilization
13	Prevalence of anemia among pregnant women (x_{33})	(-.497)			
14	Prevalence of anemia among children under 5 years of age (x_{34})	(-.518)			
15	Cereal import dependency ratio (x_{41})	(-.614)	(.165)		
16	Value of food imports over total merchandise exports (x_{42})	(-.664)	(-.332)	.25	Stability
17	Per capita food production variability (x_{43})	(.414)	(-.482)		
18	Per capita food supply variability (x_{44})	(-.102)	(-.794)		

* Opposite sign for all values in the parenthesis to reflect relationship with food security

The next step applies the output of the PCA that determines the variables that are key indicators for food security and the weight for each indicator. Only 18 of 31 indicators are used for the index of food security. The index of food security was generated for several countries from different parts of the world during the period from 2000 to 2011 by using the flowing equation:

$$FS_{Avaliablity,\, ij} = (.433 \cdot x_{11}) + (.366 \cdot x_{12}) + (-.449 \cdot x_{13}) + (.484 \cdot x_{14}) + (.491 \cdot x_{15}), \qquad (1.17)$$

$$FS_{Access,\, ij} = (.415 \cdot x_{21}) + (.448 \cdot x_{22}) + (.478 \cdot x_{23}) + (.466 \cdot x_{24}) + (-.427 \cdot x_{25}),$$

$$FS_{Utlization,\, ij} = (.476 \cdot x_{31}) + (.509 \cdot x_{31}) + (-.497 \bullet x_{33}) + (-.518 \cdot x_{34}),$$

and

$$FS_{Stability,\, ij} = (35.99/65.87)\,[(-.614 \bullet x_{41}) + (-.664 \bullet x_{42}) + (.414 \bullet x_{43}) + (-.102 \bullet x_{44})]$$

$$+ (29.8/65.87)\,[(.165 \bullet x_{41}) + (-.332 \bullet x_{42}) + (-.482 \bullet x_{43}) + (-.794 \bullet x_{44})].$$

Then, I apply equations 1.17, which weigh different indicators of food security, inside equation 1.12 to weigh the four dimensions and calculate the score of food security. Table 1.18 displays values for the food security index for the 59 countries in the study. The results show negative values for the index for some countries because the PCA uses standard values for all variables.

The food security index shows growth for most of countries as displayed in Table 1.18. The ranking of countries according to multi-dimensions food security in 2011 obtained in this study does correspond with the ranking of countries provided by the Global Food Security Index (GFSI) in 2012 using the data of 2011 for some countries. In general, the developed countries come in the top ranking of these two indexes. The differences in the ranking of countries between various indexes is because of the different factors being used and of the different procedures being followed—this study uses 18 indicators for 4 dimensions of food security, while GFSI use 25 indicators for 3 dimensions of food security.

Table 1.18. Food Security Index Value across different Countries between 2000 and 2011.

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	RANK 2011	EIU 2012*
Algeria	-1.12	-1.09	-1.09	-0.99	-0.95	-0.92	-0.84	-0.87	-0.86	-0.84	-0.80	-0.74	47	73-46
Austria	1.66	1.63	1.62	1.71	1.58	1.54	1.58	1.68	1.67	1.66	1.66	1.69	4	6-6
Belarus	-0.43	-0.59	-0.50	-0.30	-0.27	-0.10	0.02	0.10	0.00	0.09	0.26	0.38	29	43-33
Belgium	2.03	2.06	2.03	2.05	2.03	2.03	2.01	1.99	2.03	2.00	1.98	1.97	1	12-11
Bolivia	-2.31	-2.20	-2.15	-2.10	-1.96	-2.01	-1.99	-1.96	-1.80	-1.74	-1.71	-1.69	54	65-43
Brazil	-0.36	-0.32	-0.27	-0.17	-0.20	-0.18	-0.16	-0.10	0.01	0.07	0.16	0.19	34	31-28
Bulgaria	-0.10	-0.14	-0.12	0.06	0.06	0.10	0.07	0.08	0.08	0.07	0.16	0.20	33	46-35
Canada	1.11	1.15	1.27	1.25	1.23	1.25	1.23	1.20	1.21	1.19	1.17	1.18	15	8-8
Chile	-0.14	-0.10	-0.05	0.00	0.06	0.13	0.13	0.14	0.15	0.13	0.07	0.09	35	26-23
Colombia	-1.05	-1.01	-0.98	-0.95	-0.88	-0.86	-0.88	-0.79	-0.75	-0.75	-0.77	-0.81	48	51-39
Costa Rica	-0.58	-0.55	-0.57	-0.56	-0.61	-0.62	-0.55	-0.32	-0.33	-0.29	-0.24	-0.24	39	35-30
Czech	0.95	0.83	0.91	0.98	1.05	1.09	1.22	1.29	1.25	1.25	1.30	1.36	12	23-20
Denmark	1.73	1.74	1.80	1.81	1.87	1.88	1.89	1.93	1.86	1.77	1.74	1.75	3	2-2
El Salvador	-1.56	-1.55	-1.56	-1.57	-1.45	-1.36	-1.35	-1.31	-1.23	-1.14	-1.03	-1.06	51	56-41
Estonia	-0.41	-0.40	-0.20	-0.11	-0.07	0.13	0.27	0.40	0.37	0.36	0.35	0.38	28	-
Ethiopia	-4.03	-4.16	-3.79	-3.54	-3.31	-3.32	-3.50	-3.52	-3.49	-3.31	-3.14	-2.95	58	100-49
Finland	0.81	0.85	0.99	0.99	1.02	1.05	1.07	1.09	1.06	1.07	1.06	1.07	16	9-9
France	1.92	1.91	1.90	1.91	1.88	1.81	1.72	1.69	1.69	1.74	1.76	1.76	2	4-4
Germany	1.47	1.47	1.51	1.56	1.55	1.58	1.60	1.62	1.65	1.66	1.66	1.64	7	10-10
Greece	0.94	0.96	0.94	0.95	1.05	0.98	0.97	0.85	0.80	0.81	0.97	0.95	18	18-16
Hungary	0.82	0.67	0.77	0.75	0.79	0.81	0.79	0.77	0.84	0.94	0.86	0.75	24	25-22
India	-2.24	-2.21	-2.22	-2.25	-2.26	-2.23	-2.13	-2.05	-2.07	-2.03	-1.94	-1.80	56	66-44
Indonesia	-1.94	-1.90	-1.83	-1.73	-1.65	-1.60	-1.56	-1.50	-1.45	-1.40	-1.38	-1.34	53	64-42
Iran	-0.97	-0.93	-0.92	-0.85	-0.80	-0.75	-0.72	-0.41	-0.38	-0.32	-0.27	-0.29	40	-
Italy	1.37	1.42	1.45	1.51	1.46	1.47	1.44	1.44	1.45	1.43	1.44	1.42	9	19-17
Japan	0.57	0.59	0.60	0.61	0.60	0.58	0.57	0.55	0.50	0.44	0.37	0.36	30	16-14
Jordan	-0.99	-0.91	-0.86	-0.82	-0.88	-0.86	-0.76	-0.69	-0.61	-0.70	-0.71	-0.68	46	54-40
Kuwait	0.59	0.60	0.59	0.60	0.63	0.74	0.86	1.03	0.94	0.84	0.75	0.78	22	-
Laos	-3.08	-2.98	-2.88	-2.77	-2.68	-2.56	-2.51	-2.42	-2.36	-2.31	-2.24	-2.14	57	-
Latvia	-0.86	-0.71	-0.38	-0.02	0.16	0.24	0.34	0.39	0.49	0.55	0.70	0.75	23	-

Table 1.18. Food Security Index Value across Different Countries between 2000 and 2011 (Continue).

Country	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**RANK 2011**	**EIU 2012***
Lithuania	-0.27	-0.38	-0.24	-0.03	0.15	0.32	0.47	0.60	0.59	0.80	0.90	0.83	20	-
Malaysia	-0.21	-0.23	-0.23	-0.25	-0.22	-0.11	-0.07	-0.06	-0.04	-0.02	-0.01	0.03	36	33-29
Malta	1.22	1.16	1.13	1.12	1.15	1.21	1.41	1.40	1.43	1.44	1.43	1.41	10	-
Mexico	-0.49	-0.45	-0.45	-0.42	-0.37	-0.25	-0.24	-0.20	-0.13	-0.09	-0.08	-0.08	37	30-27
Morocco	-1.48	-1.42	-1.36	-1.29	-1.17	-1.21	-1.14	-1.16	-1.10	-1.02	-0.94	-0.88	49	59-42
Netherlands	1.71	1.71	1.72	1.65	1.63	1.63	1.67	1.67	1.64	1.67	1.72	1.69	5	5-5
Nicaragua	-1.98	-1.91	-1.89	-1.76	-1.69	-1.61	-1.58	-1.48	-1.39	-1.33	-1.27	-1.21	52	69-45
Norway	1.09	1.16	1.16	1.16	1.18	1.23	1.22	1.20	1.17	1.16	1.18	1.23	14	3-3
Oman	-0.95	-0.87	-0.87	-0.71	-0.74	-0.70	-0.68	-0.50	-0.38	-0.34	-0.31	-0.31	41	-
Pakistan	-1.80	-1.77	-1.83	-1.90	-1.93	-1.86	-1.83	-1.85	-1.82	-1.77	-1.75	-1.74	55	75-47
Paraguay	-0.87	-0.81	-0.74	-0.67	-0.72	-0.67	-0.65	-0.42	-0.60	-0.44	-0.50	-0.45	42	49-37
Peru	-1.78	-1.72	-1.65	-1.60	-1.62	-1.60	-1.46	-1.36	-1.26	-1.17	-1.00	-0.96	50	48-36
Poland	0.58	0.54	0.57	0.66	0.69	0.67	0.63	0.62	0.66	0.71	0.76	0.81	21	24-21
Portugal	0.78	0.81	0.81	0.92	0.93	0.89	0.89	0.91	0.89	0.99	0.96	0.93	19	15-13
Re. of Korea	0.25	0.30	0.34	0.36	0.41	0.46	0.52	0.58	0.64	0.65	0.66	0.63	25	21-19
Moldova	-1.63	-1.51	-1.36	-1.22	-1.14	-0.87	-0.78	-0.76	-0.77	-0.76	-0.68	-0.59	44	-
Russia	-0.86	-0.66	-0.50	-0.31	-0.14	0.02	0.00	0.05	0.05	0.10	0.21	0.25	31	29-26
Saudi Arabia	-0.71	-0.66	-0.60	-0.62	-0.66	-0.73	-0.68	-0.58	-0.55	-0.55	-0.54	-0.50	43	28-25
Senegal	-3.56	-3.53	-3.57	-3.65	-3.67	-3.68	-3.76	-3.70	-3.55	-3.45	-3.41	-3.38	59	93-48
Slovakia	0.31	0.20	0.13	0.18	0.29	0.42	0.44	0.47	0.44	0.47	0.49	0.45	26	27-24
South Africa	-0.84	-0.86	-0.82	-0.78	-0.78	-0.76	-0.76	-0.75	-0.75	-0.76	-0.69	-0.66	45	40-32
Spain	1.40	1.45	1.47	1.53	1.53	1.49	1.45	1.41	1.39	1.30	1.29	1.29	13	13-12
Sweden	0.99	1.01	1.05	1.08	1.13	1.13	1.13	1.09	1.05	1.03	1.06	1.06	17	17-15
Switzerland	1.51	1.40	1.43	1.41	1.44	1.50	1.50	1.55	1.57	1.59	1.59	1.60	8	7-7
Tunisia	-0.55	-0.50	-0.48	-0.50	-0.52	-0.36	-0.35	-0.31	-0.24	-0.22	-0.26	-0.20	38	50-38
Turkey	0.14	0.13	0.13	0.17	0.19	0.29	0.33	0.32	0.32	0.34	0.39	0.45	27	36-31
Ukraine	-0.75	-0.51	-0.30	-0.10	0.02	0.00	0.08	0.06	0.11	0.27	0.27	0.22	32	44-34
United Kingdom	1.28	1.38	1.41	1.42	1.43	1.47	1.55	1.47	1.43	1.38	1.63	1.38	11	20-18
United States	1.81	1.78	1.82	1.80	1.85	1.90	1.88	1.93	1.89	1.76	1.68	1.68	6	1-1

*****Use the data of 2011.

1.7.7 Food Security Index and the 2007–2008 Economic Crisis

The economic crisis and spikes of food prices in the international market occured in 2007–2008 and 2011 (FAO, 2009; Global Food Security, 2014). On the global level, the FAO food price index showed an increase by 26% in 2007 and 58% in 2008 compared with the same index in 2006. There is a small decrease in 2009, followed by an increase to arrive to the peak in 2011, which is about an 81% increase in prices compared with the prices in 2006. The high spike of food price is the result of different factors, such as low food production and food stocks due to weather and climate conditions, along with an increase in the production of biofuels and biomass, rising oil prices, and depreciating US dollar (Global Food Security, 2014).

According to the FAO data I used in this study to construct food security index, the effect of price on a national level of food security represents a domestic food price level index. This index indicates the change in food prices for a country; an increase in this change will reflect the difficulties for people who live in a country to access food, which finally affects food security. The average change for all countries in the domestic food price level index did not increase during economy crisis and price spikes (2007/2008). This indicator is measured by the ratio of a country's food consumer price index (FPI) and general consumer price index (CPI) using a 2011 base year relative to the United States for each year to avoid the impact of inflation. Therefore, this indicator does not show price changes during the time change, while it shows the change in price from one country to another during a year. In conclusion, the food security index in this chapter is not affected by the inflation in food prices.

1.8 Summary

The first part of this research employed PCA to build a new food security index. The objective of the analysis is to provide the variables that build food security index and the way to weigh them that allows a national-level comparison of countries from different parts of the world. These data will be used in subsequent parts of this research to look the association between overall food security index and four pillars of food security with dietary diversity at the national level in different countries. To build the index, PCA was used to evaluate the contribution of all 31 indicators of the four dimensions of food security (food availability, food accessibility, food utilization, and stability) represented in the FAO dataset (FAO, 1990–2015) during the period of time between 1990 and 2011. Standardized measures of different variables were used to identify the indicators that can contribute to food security development and make it easy and reasonable to form one index. The results conclude the 18 variables share the effect of different food security dimensions. Finally, all of these indicators were combined into a single measure to reflect a multidimensional index of food security for the 59 countries represented in the study.

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Chapter 2: The Relationship Between Dietary Diversity and Food Security Dimensions

2.1 Introduction

Many different methods have been proposed as food security measures across many countries for years. However, there is not one "best" measure for determining the level of food security. Dietary diversity is one common indicator of food security because it identifies food consumption behaviors. An increase in this indicator can be used as evidence that individuals or households are better equipped to satisfy their food needs. The other way to measure food security is building complex indices based on several dimensions and using indicators for each dimension as in the previous chapter, in which an index was designed using the four pillars of food security: availability, accessibility, utility, and stability.

Dietary diversity is one popular indicator of food security, and it could be associated with any of the four pillars. Some indicators of food security may affect or be affected by dietary diversity. To be sure, we need to look at a correlation between the composite scores of multiple indicators of the food security index and the dietary diversity index. Additionally, this correlation can be examined in a disaggregated way by looking at the individual pillars of food security and their relationships to dietary diversity.

In order to analyze the associations between the comprehensive indices of food security and dietary diversity, we must first measure them. In the first chapter, I created a food security index and measured it for several countries. In this chapter, I will measure dietary diversity by using various indices, such as the Shannon and Simpson Diversity indices, for the same countries after dividing food items into common consumption categories, such as rice, wheat, fruit and vegetables, sugars and sweeteners, starchy roots, and animal products, in order to examine the diversity of food consumption in each country and their respective links to food security. Then, I will determine the links between the changes in overall food security indices at each level of the food security pillars (availability, accessibility, utility, and stability) and dietary diversity by using correlation coefficients, such as Pearson's and Spearman's coefficients, and linear regressions to determine the strengths of these associations throughout the countries.

2.1.1 Dietary Diversity Definition

In general, dietary diversity measures the number of food groups consumed by individuals or households over a period of time. The range of these time periods can span from 24 hours to 15 days (Drewnowski et al., 1997).

In the literature, the definition of dietary diversity (DD) changes depending on the research goal. Some research measures the diversity of actual consumption for individuals given a reference time period, which provides direct information about the accessibility of food and the effects of dietary diversity on health. However, other studies measure dietary diversity in a way that can provide us with the food choices, based on the time period, available to an individual for consumption by calculating the diversity of the food supply in their country, which presents the historical data of diversity where data is typically unavailable.

2.2 Literature Review

2.2.1 Diversity in General

The abundance of different groups and types of ideas, cultures, education levels, effective economic sectors, and demographics are examples of diversity among individuals or at the country level. In general, diversity is recommended in order to obtain the advantages of mixing different types of things (Phillips, 2014).

2.2.2 Dietary Diversity: Goals, Methods, and Types of Food

The goals of studies on dietary diversity can vary immensely. The main goal is to learn the shapes of dietary diversity and whether there are high levels of diversity. Ajani (2010) used a survey from six states in Nigeria to assess the dietary diversity in the past consumption in 24 hours of 14 food groups. In general, he found a medium level of dietary diversity in each state. More than 80% of individuals consumed between five and nine food groups, but there were some differences in dietary diversity between the Nigerian states.

In more advanced studies, some have researched the relationship between dietary diversity and other factors. One of these factors, which may affect the level of dietary diversity in production-based countries, is crop diversity in farms (Rajendran et al., 2014). The researchers used a simple count of the consumption of each food group to measure dietary diversity in 24 hours, then used the crop count and Simpson's Index as two different ways to measure farm diversity. Their analysis, using correlations and multiple linear regressions for cross-sectional data, found that farm diversity is not related to the dietary diversity of households. In addition, diets are affected by several other variables, such as changes in incomes and prices, differences in preferences and beliefs, geographical and environmental locations, and other social and economic factors (World Health Organization, 2009). Therefore, the influence of socioeconomic factors on dietary diversity is the main topic for many studies. Rajendran et al. (2014) also explored the relationship between dietary diversity and some characteristics of individuals and households that include some of the factors in their model, such as household sizes, levels of education, and food expenditures. They emphasized the influence of these variables on the level of dietary diversity. However, Hatloy et al. (2000) look at this association by using assets as a proxy for income level. This research divides subjects into household that own 0–3, 4–6, and 7–

10 assets from 14 total assets that are included in the study. In addition, they measure dietary diversity in items (or food variety scores) and groups (or dietary diversity scores) for previous household consumption in 24 hours. The study shows the positive relationship between the diversity of consumption in food variety scores and dietary diversity scores with assets in urban and rural areas of Mali. In addition, this study finds a higher level of dietary diversity in urban areas than rural areas.

The other important economic factor that could affect dietary diversity is price. The global economic and financial crisis in 2007 and 2008 encouraged Brinkmanet al. (2010) to study the impact of high food prices on food consumption in the developing world. They used food consumption scores to measure dietary diversity. By using a linear regression, they found a negative correlation between dietary diversity and food prices, in which households reduce their dietary diversity along with increases in prices for their main food staples. Others have targeted the association between food consumption patterns and income and price changes, and Regmiet al. (2001) confirmed this association by using cross-country analyses of seven food groups. They found that the share of income spent on food increased as income went down and low-income countries were more sensitive when prices changed, especially with expensive foods, while they were less sensitive with staple foods. Leatherman (1994) confirmed this increase in dietary diversity in urban areas compared to rural areas in the same country. This study also confirmed the other effects of socioeconomic factors, such as income and gender, in the southern Andes. People with high incomes had more dietary diversity than people with lower incomes. As for the gender effect, the case study found that men were consuming less meat, dairy products, and vegetables. Clausen et al. (2005) also found that older people living in urban areas and cattle owners with higher education level had higher food variety scores. In a case study in Iran, researchers found the effects of socioeconomic factors, such as age, BMI, education level, and job status, on their dietary diversity scores (Mirmiran et al., 2006). Thorne-Lyman et al. (2010) used a simple dietary diversity score as an indicator of food security to explore the association between some indicators of socioeconomic status in Bangladesh. The socioeconomic factors represented were wealth, education level, living area, sex of the head of household, and family size. More specifically, the per-capita non-grain food expenditures, total food expenditures, and total household expenditures were the proxies of household wealth. The study built upon the Spearman Correlation as a method of studying this association, and they depended on seven food groups consumed over seven days. The study found a positive medium association (0.3–0.4) between wealth and dietary diversity scores and a positive small association with other socioeconomic factors.

2.2.3 Dietary Diversity as a Food Security Indicator

There are many studies that use dietary diversity as a food security indicator in addition to using dietary diversity as an indicator of nutrient adequacy and quality of diet. Hoddinott and Yohannes (2002) used data from 10 countries to investigate dietary diversity as an indicator of household food security in the accessibility dimension. The included countries contained poor- and middle-income households, and the study collected information on calories consumed in rural and urban areas across different seasons and used both seven-day and 24-hour periods of food consumption. Linear regression techniques and correlations were used to examine the association between dietary diversity and food security. The study used several indicators for household food security, including household per capita consumption, household per capita daily availability, household per capita daily caloric availability from staple foods, and household per capita daily caloric availability from non-staple foods. The association between dietary diversity and all of these indicators of food security was confirmed with different percentages of effect. Lele et al. (2016) reviewed 33 indicators of nutrition and food security used by different researchers. These indicators can be used for measurements on individual, household, market, and national levels and represent the four food security pillars. These indicators of food security can be single or multidimensional, like those that appear on the Global Hunger Index and the Global Food Security Index. One of the national indicators of food security is dietary diversity built on dietary energy in food supplies for the Food Agricultural Organization's Food Balance Sheet database using the Shannon Entropy Index.

One of the interesting questions raised in Ruel's paper (2003) is whether there is an association between dietary diversity and food security. He reviewed many studies in multiple countries and then found a strong association between dietary diversity and many indicators of food security, such as per capita consumption and energy availability, which indicated that dietary diversity could be a measure of household food security. As dietary diversity is not the only measurement tool for food security, Assenga and Kayunze (2016) compared the different methods that could be used to determine food security using cross-sectional household survey data. The three indicators of food security included in their study were dietary energy consumption (DEC), dietary diversity (DD), and the household food insecurity access scale (HFIAS). The results of the study showed that DEC and HFIAS provided almost the same results of food security status while DD gave an exaggerated measure of food insecurity situations. The researchers recommended using DEC as an indicator of food security, which is what I use in this chapter, with modification, by using the diversity of dietary energy consumption. In a similar way to the previous study, Kirkland et al. (2013) examined the associations between different indicators used to evaluate food security by using a household survey (self-reported behaviors) that targeted rural areas in South Africa. These indicators were experiences of hunger, dietary diversity, and coping strategies. The study mentioned that dietary diversity is a good indicator and has more overlap with the other two indicators of household food security.

2.2.4 The Relationship Between Dietary Diversity and Other Food Security Dimensions

The relationship between dietary diversity and the separate food security pillars has been investigated in some studies. For example, one study analyzed household food consumption in Kenya to determine the pattern of consumption and access to different types of food (Ofwona, 2013). This kind of study that focuses on food patterns is important for governments to implement policies that enhance dietary consumption by improving accessibility to food for more households, which is one of the food security pillars. A study that assessed the outcome of the Chars Livelihood Program (CLP) used three dimensions of food security: accessibility of food, food availability, and food utility (Cordier et al., 2012). For food accessibility, the researchers used dietary diversity as one indicator of this dimension.

2.2.5 The Effects of Other Variables on Food Security Dimensions

The researchers also attempted to find the impact of several variables on multiple dimensions of food security instead of on overall food security. The study of changing technology adoption on different food security pillars is one example. Vigani and Magrini (2014) used the improvement of maize seeds and inorganic fertilizer as an index of changes in agricultural technologies to estimate the causal effect on food security dimensions for Tanzanian households. They observed significant positive effects of technology on availability, accessibility, and utility dimensions. While only improving seeds decreased the stability, inorganic fertilizers led to improved resilience. Maxwell et al. (2013) compared measures of household food security in general, while specifically identifying the associations between these indicators of food security dimensions. They surveyed households in four rounds, which they paneled from data collected in the north of Ethiopia. The methods of finding food security included the coping strategies index (CSI), reduced coping strategies index (rCSI), household food insecurity and access scale (HFIAS), household hunger index (HHI), food consumption score (FCS), household dietary diversity scale (HDDS), and a self-assessed measure of food security. The relationship was examined by using a non-parametric method (the Spearman Correlation). This test confirmed the strong significant correlation between these indicators of food security, and the association was not affected by seasons. These indicators are useful for food security measurements and suggest that the indicators may measure different aspects of food security, so the researchers studied the relationship between different measures and food security dimensions. The dimensions of food security used in this study included quantity, quality, acceptability, safety, and stability. The analysis found that some measurement tools of food security captured every dimension. For example, FCS and HDDS had a strong correlation with quality dimensions, as opposed to the quantity correlated between CSI and rCSI.

2.2.6 Models of Diversity

In 1981, Guthrie and Scheer measured the consumption rates of four food groups over 24 hours with the same weight to calculate their dietary scores. More recent studies have used a scoring system that takes the consumption amounts of different food groups included in the model into consideration for measuring dietary diversity. Tian et al. (2015) analyzed dietary diversity in China with four different methods that used different scoring systems from sample counts of food items and food groups to make a model for scoring dietary diversity. These models appear in the count index, dietary diversity index, Shannon Entropy Index, and Simpson Index. The results of this study concluded that dietary diversity improves over time in China.

Furthermore, they used food facilities (restaurants and supermarkets) as indices of food access. Their study concluded that, probably not surprisingly, living near a large number of facilities led to improvements in dietary diversity along with the effects of other socioeconomic factors, such as income, gender, age, household size, education, and region. In another study, the researcher reviewed the three types of models to measure dietary diversity (the Herfindahl Index, Simpson Index, and Entropy Index) and finally used the Entropy Index to measure the expenditure shares of different food groups and items (Das, 2014). He depended on data from four rounds of national household consumption surveys in India to compare different regions and analyze variables that impact dietary diversity. The results concluded that there was heterogeneous dietary diversity across different regions in the country, while the quantile regression confirmed that dietary diversity is most affected by the levels of consumption expenditure, food quality adjusted with unit values, education, and information distribution. In addition, Parappurathu et al. (2015) focused on households in the eastern region of India and calculated dietary diversity by using the Simpson Index. Then, they used multiple linear regression models to examine the association between socioeconomic factors and dietary diversity. On a national level, Remans et al. (2014) used several ecological diversity matrices to look at the nutritional diversity distribution across countries, which is related to health outcomes, and whether there is a relationship between the diversity of food production and food supply. They used the Shannon Entropy Index, the Modified Functional Attribute Diversity, and the percentage of energy coming from non-staple foods as methods to measure diversity. They concluded that there is a strong association between nutritional diversity and human health outcomes. In addition, agricultural production dominates national food supplies for low-income countries, while trade leads in middle- and high-income countries. Katanoda et al. (2006) adjusted the Simpson Index to measure diversity and used their new index to examine and compare the diversity from energy and nutrient intake with different food groups across different periods of time and countries. They used data from a national survey in Japan and determined the increase in diversity between the 1960s and 1970s. Another study combined health values and food diversity to construct a new, healthy food diversity index (Drescher et al., 2007).

Additionally, previous studies have created variation in their methods by using food groups and food items. Hatloy et al. (1998) studied comparisons between using food groups and individual items of food to measure dietary diversity scores. They determined a food variety score by simply counting the food and dietary diversity scores depending on eight food groups. They found that the dietary diversity scores had significant determinants of nutrient adequacy compared to food variety scores. In a similar study, Ogle et al. (2001) used 12 food groups and more than 120 items of food in their seven-day consumption survey. The study found that adult women in Vietnam had higher adequacy ratios for energy, protein, niacin, vitamin C, and zinc, whether they consumed eight food groups or 21 items. In general, the relationship between dietary diversity and nutrient adequacy has a positive association after reviewing research that focuses on developing countries (Ruel, 2003).

In addition, earlier research differed in respect to food groups, periods of consumption, scoring systems, and group study characteristics. Oldewage-Theron and Kruger (2008) used food variety and dietary diversity scores as indicators of dietary adequacy. They used 24-hour recall questionnaires about food consumption, socio-demographics, and other questions for elderly people in Sharpeville, South Africa. Results of this study explored those in the community suffering from household food insecurity. In addition, this study found a positive association for food variety and dietary diversity, with dietary adequacy, which means both of food variety and dietary diversity could assess of the adequacy of the diet. Furthermore, they recommend dietary diversity score is a simple tool to measure risk of food and nutrition insecurity for elderly people. Another group of researchers investigated the consumption of food items, food variety scores, and food groups in dietary diversity scores to investigate the association between the physical and cognitive functioning of older adults in Botswana (Clausen et al., 2005). They used 16 food items that are consumed in categories for food variety scores while counting the weekly consumption of five food groups: grains, meats, vegetables, fruits, and dairy. In general, the study found a lack of dietary variety for older people in Botswana and a positive association between food variety scores, health, and cognitive functions. In another study, Mirmiran et al. (2006) targeted women in Tehran, Iran, to determine the relationship between dietary diversity and nutrient adequacy. They used cross-sectioned data and 24-hour recall questionnaires. They concluded a strong association between dietary diversity scores and improved nutrient adequacy in general and determined that they could use dietary diversity scores as indicators for nutrient adequacy. More specifically, there was a stronger correlation between grain diversity scores with vitamin B_2, fruit diversity scores with vitamin C, diary diversity scores with calcium intakes, and meat diversity scores with protein intakes. By focusing on women who lived in rural areas in northeast Burkina Faso, Savy et al. (2005) compared food variety scores to dietary diversity scores as good indicators for dietary quality. They used a simple count for the previous 24 hours of consumption among different items and 14 food groups, but this study did not take into account the frequency or amounts of food consumption. The dietary quality was divided into high, medium, and low categories depending on the diversity of consumption for both items and groups. The study used body mass index, mid- and upper-arm circumference, and body fat percentage as indicators of nutritional status. The results of this study indicated that the dietary diversity score was the better and simpler indicator for measuring dietary quality, which also correlated to nutritional status.

If dietary diversity is measured in groups, the next question is: What are the best segments for food consumption? The answer is that food groups depend on the purpose of the study, according to previous research. The nutrient contents and contributions of specific food groups on the nutrients provide the rules for dividing food groups if they need dietary diversity to indicate nutrient adequacy (Ruel, 2003). For other goals, such as measuring household food security or the effects of socioeconomic factors, dietary diversity is preferable to building food groups with economic values. The same previous study did not come to a conclusion on some aggregations of food, such as whether meats include fish or poultry and whether dietary products include eggs. For example, the study by Tian et al. (2015) divided food groups for dietary diversity scores into six groups—grains; vegetables; fruits; meat, poultry, and seafood; dairy; and beans, eggs, and nuts. A study of food consumption patterns across 114 countries (Seale et al., 2003) examined nine food groups: breads and cereals, meat, fish, dairy products, oils and fats, fruits and vegetables, beverages and tobacco, and other food products.

Another study used the food groups from the FAO's balance sheet (Hoddinott and Yohannes, 2002). The study measured household dietary diversity by using 12 groups of food consumption. Moltedo et al. (2014) compared the different resources to make a dietary diversity score that could assess food security through nutritional dietary surveys, national household surveys, and food balance sheets. The greatest advantage of the food balance sheets is that they cover almost all countries since 1980 at a national level and capture all food consumption from a supply perspective, which includes private households and public establishments. The downsides of this method of collecting a dietary diversity score are that it does not capture the distribution of food through populations and that it covers the supply side instead of the demand side. In addition, it does not include food that was produced and consumed by households.

However, this model of dietary diversity has been proven as a better method of choosing food groups, scoring systems, reference periods, and relative issues by additional researchers and is a more valid indicator of different research purposes (Ruel, 2003). Now, this chapter will move onto examining dietary diversity as a measurement of food security.

2.3 Reasons for Choosing Dietary Diversity as an Indicator of Food Security

It is typical for studies to use dietary diversity as an indicator of food security, and I reviewed these studies previously. These studies proved the reasons for connecting dietary diversity to other indicators of food security, and the most suitable indicator is the multidimensional index that includes all four food security pillars (availability, accessibility, utility, and stability).

First, the indicators of the availability of food have an effect on dietary diversity, which could positively change the dietary diversity when the change occurs in energy or protein supplies from different resources. Another indicator of food availability is the value of food production, which reflects the amount of food available and the ability to diversify the food in a specific country. The second dimension of food security is the access to food, for which the impact of dietary diversity can speak to the effects of physical and economic access. However, improved roads and increased rail-line densities as indicators of physical food access can create more food diversity for individuals and households. Furthermore, economic factors, such as the growth of GDP as a proxy of individual incomes and the stability of price, can also contribute to the variation in food supplies and consumption. In addition, some utilization indicators can provide evidence of a higher level of dietary diversity, a connection that has been confirmed by many researchers. Food consumption from different resources will allow people to take advantage of the contents of different foods, such as vitamins and proteins, which can enhance health and reduce illness. Finally, more stability and less volatility in prices, production, and political systems make it clear that one factor can lead to at least keeping a steady level of dietary diversity.

2.4 Study Gap

This study uses dietary diversity as an indicator of food security that has already been used in several studies on the household level, but the construction here is different than dietary diversity used by others. This case study contains all households on a national level and uses sources of the diversity of energy intake (I will call it "dietary diversity" in this paper) to reflect food security rather than questions of the food consumption of particular households or part of a country. This measurement can be used to compare different countries.

2.5 Study Objective

The multidimensional food security index is an important measurement of food security that takes into account all four pillars of food security with different indicators that have led to improvements or have evidence of improving food security. On the other side, this index faces many problems with collecting and analyzing data. Therefore, the use of dietary diversity on a national level could be the key to determining the food security level from several studies. From this point on, it will be helpful to examine the relationship between dietary diversity and comprehensive food security scores derived from indicators of the food security pillars across the countries from the last chapter, then to decide whether the measurement of dietary diversity represents all dimensions of food security. Dietary diversity could contribute to improving some food security indicators included in the food security pillars, such as the utility dimension. On the other hand, some variables used in food security scores could lead to changes in dietary diversity levels, such as the accessibility dimension. Accordingly, measuring this relationship is akin to exploring the strength of the correlation between these indicators of food security and dietary diversity. In conclusion, the hypothesis of this study is that the measurement of dietary diversity will be enough to reflect the overall changes in food security and each food security dimension.

2.6 Methodology

2.6.1 Dietary Diversity Model

As this chapter aims to measure dietary diversity (DD) for several countries and explore the association with the food security index and each food security pillar, I will use the following procedures: collecting data on the energy intake of subgroups of food and calculating the dietary diversity index, then determining whether it has an association with the multidimensional food security index.

First, I collected the data for dietary energy supplies from the recorded consumption of items and food groups for the study sample on a countrywide level. This data came from Food Balance Sheets (FBS), which recorded the food available for consumption, issued by the FAO. The advantage of using this data is that it will provide historical data on the available food in each country, but the downsides are that it can create a potential for food waste and losses at the retail level and that the consumption variation of commodities can vary in different regions inside each country, whereas each region has a consumption concentration from one crop

(Moltedo et al., 2014). The data is expressed in an average of kilocalories (kcals) per capita per day for every year on the national level. The supply of food items has been divided into the most common and consistent categories of consumption. The food consumption categories appear as rice, wheat, fruits and vegetables, sugars and sweeteners, starchy roots, and animal products. The cereals are divided into two categories, rice and wheat, because 50% of the dietary energy supply comes from cereal (World Health Organization, 2009).

Second, I use several diversity indices to measure the food consumption diversity in each country. These indices not only count the consumption items, but also take into account the distribution for each item.

- Shannon's Diversity Index (1949): $H = -\sum_{i=1}^{S} r_i \ln r_i$

$$r_i = {}^{n_i}/_{N} \tag{2.1}$$

where r_i is the average proportion of calories per capita supplied in each country from one type of food per day (n_i) to the total calorie supply per day (N) and S is the number of food categories. When the supply of calories from all types of food is the same, the Shannon Index is equal to the natural log of the number of food categories, ln(S). On the other hand, zero is the value when there is no diversity in consumption. For easy comparison and interpretation, Shannon's Equitability (EH) converts the Shannon Index to a value between 1 as the highest diversity value to 0 as the lowest value (no diversity). This measure divides the Shannon Diversity Index (H) into a maximum possible value of index H_{max}, which equals ln(S).

- Shannon's Equitability (EH): $E_H = H/H_{max}$ where H_{max} = ln(s)

(2.2)

- Simpson's Diversity Index (1949): $D = 1 - \frac{\sum n(n-1)}{N(N-1)}$

(2.3)

The Simpson Index provides another way to measure dietary diversity, where n, as in the Shannon Index, represents an energy intake measure of calories from a specific food and N measures the total calories from all types of food consumption.

- Quantitative Index for Dietary Diversity (2006): $\text{QUANTIDD} = \frac{1-\sum_{i=1}^{s} {r_i}^2}{1-\frac{1}{S}}$

$$(2.4)$$

The Quantitative Index for Dietary Diversity was proposed by Katanoda et al. (2006). They used this variable to measure dietary diversity in Japan. The notations in this equation are the same as in the previous indices.

2.6.2 Analysis Model

The previous studies used dietary diversity as a measurement tool for a food security index (Ruel, 2003; Hoddinott and Yohannes, 2002; Thorne-Lyman et al., 2010; Kirkland et al., 2013; Assenga and Kayunze, 2016; and Lele et al., 2016). Therefore, this part of the chapter will focus on and explore the impact of the multidimensional food security index as an individual dimension (of availability, accessibility, utility, and stability) and an aggregation index of the food security pillars along with dietary diversity. I will use the correlation measurement and linear regressions to test this association.

One model that looks at linear relationships through correlation is the Pearson Model, which uses an interval scale, while the Spearman Model uses a non-parametric measure of correlation between the variables that use ordinal scales. The Pearson Correlation Coefficient (γ) is used to measure the linear correlation between two variables and it assumes the normal distribution of these variables. The measurement uses the following function:

- $$\gamma = \frac{n\Sigma x_i y_i - \Sigma x_i \Sigma y_i}{\sqrt{[n\Sigma x_i^2 - (\Sigma x_i)^2][n\Sigma y_i^2 - (\Sigma y_i)^2]}}$$

(2.5)

The strength and direction of the correlation are determined by the final result of equation (2.5), where COR represents the correlation value between +1 or -1 for a strong positive or negative correlation, respectively, and 0 for no association between the food security index (x) and dietary diversity (y) for n observations. The Spearman Rank Order Correlation (ρ) provides another way to assess the correlation between these variables. This model represents a special case of the Pearson Correlation Model, where the Spearman Model measures the correlation between ranking scores for two sets of variables. This model is a non-parametric measure of correlation and it does not assume a linear relationship or a normality of distribution. The following model calculates this correlation:

- $$\rho = 1 - \frac{6\sum d^2}{n^3 - n} \quad (2.6)$$

where the ranked scores (1, 2, 3, .., n) for two sets of variables that are X and Y, and d symbolizes the difference in the statistical rankings of corresponding variables (Chen and Popovich, 2002).

The next step is an analysis of the association between the multidimensional food security index and dietary diversity through the linear regression model and a look at the significance and strength of the relationship of the average data belonging to 59 countries between 2000 and 2011. The model is as follows:

- $$DD_i = f(Y_i) \quad (2.7)$$

where DD is the average dietary diversity score for each country (i) between 2000 and 2011. The dietary diversity score is extracted by one of the models of the diversity indices mentioned before, such as the Shannon Index (Equation 2.2), the Simpson Index (Equation 2.3), or the Quantitative Index for Dietary Diversity in Equation 2.4. The average score of each food security pillar and the aggregation of food security indices are represented by Y for each country in the same period of time.

2.7 Dietary Diversity Data Description

The source of dietary diversity refers to the supply of energy intake for several countries from taking the energy intake sources of six food groups (rice, wheat products, starchy roots, sugars and sweeteners, fruits and vegetables, and animal products), as mentioned above. The average supplies of energy intake from these six groups represent around 73% of the total energy intake supply of 59 countries in this study between 2000 and 2011. These percentages varied across countries, from 86% in Iran to only 38% in Ethiopia, but most of the countries (48) were above 70%, as illustrated in Table 2.1. The remaining percentage of energy intake may come from other energy intake sources, such as other cereal products except rice and wheat. Furthermore, the countries could have different sources of energy intake, which could be concentrated in certain food groups or items. The energy intake sources, on average, between 2000 and 2011 from several categories of food, in kilocalories per capita per day, for several countries (Brazil, Jordan, Malaysia, Mexico, Morocco, the Republic of Korea, Saudi Arabia, South Africa, Turkey, and the United States) compared to the world average in the aforementioned six categories of energy intake sources are illustrated in Figure 2.1. The figures that demonstrate the energy intake sources from different items and food groups show variation from country to country. On a global level, the average energy intake from food supplies appears not to be concentrated, and the available energy intake of all individual food categories represent less than 30% of the total. At the same time, the energy intake from rice and wheat products still represents around 50% of the total. On the national level, all countries have more than 30% of a concentration on at least one item or food group as an energy intake source in the study period. In the United States, the wheat product and sugar/sweetener groups represent 23% of energy intake sources each, while there is a high concentration of animal products that represents around 39% of energy intake sources. Brazil has a smaller concentration of energy intake from the food supply distributed between categories, but the animal products have the highest position of energy intake sources at 32%, followed by other sources, such as sugars and sweeteners, wheat products, and rice. Animal products with sugar and sweetener products are the main energy intake sources in Mexico, accounting for around 68% of the total energy intake. Turkey, Jordan, Morocco, South Africa, and Saudi Arabia each get 30–50% of their energy intake from wheat products. On the other side, the Republic of Korea and Malaysia have much of energy intake from rice, which was 37 percent in the Republic of Korea, and 35 percent in Malaysia from the total energy intake from all items and food groups for these countries. In some countries, there is a concentration of energy intake sources on animal products, such as in the United States (39%), Mexico (38%), and South Africa (27%).

Table 2.1. Average Ratio of Energy Intake from Six Food Categories to Total Supply of Energy Intake in 59 Countries Between 2000 and 2011.

Country		Percent*	Country		Percent*
1	Algeria	78%	31	Lithuania	78%
2	Austria	71%	32	Malaysia	77%
3	Belarus	72%	33	Malta	84%
4	Belgium	77%	34	Mexico	51%
5	Bolivia	76%	35	Morocco	71%
6	Brazil	69%	36	Netherlands	77%
7	Bulgaria	72%	37	Nicaragua	56%
8	Canada	71%	38	Norway	77%
9	Chile	81%	39	Oman	83%
10	Colombia	71%	40	Pakistan	80%
11	Costa Rica	76%	41	Paraguay	57%
12	Czech Republic	71%	42	Peru	77%
13	Denmark	79%	43	Poland	76%
14	El Salvador	51%	44	Portugal	73%
15	Estonia	72%	45	Republic of Korea	76%
16	Ethiopia	38%	46	Republic of Moldova	61%
17	Finland	77%	47	Russian Federation	81%
18	France	77%	48	Saudi Arabia	73%
19	Germany	72%	49	Senegal	59%
20	Greece	72%	50	Slovakia	78%
21	Hungary	77%	51	South Africa	50%
22	India	75%	52	Spain	68%
23	Indonesia	78%	53	Sweden	77%
24	Iran	86%	54	Switzerland	77%
25	Italy	74%	55	Tunisia	79%
26	Japan	72%	56	Turkey	74%
27	Jordan	79%	57	Ukraine	77%
28	Kuwait	80%	58	United Kingdom	76%
29	Laos	85%	59	United States	70%
30	Latvia	69%			

*ratio of energy intake from six food groups to total.

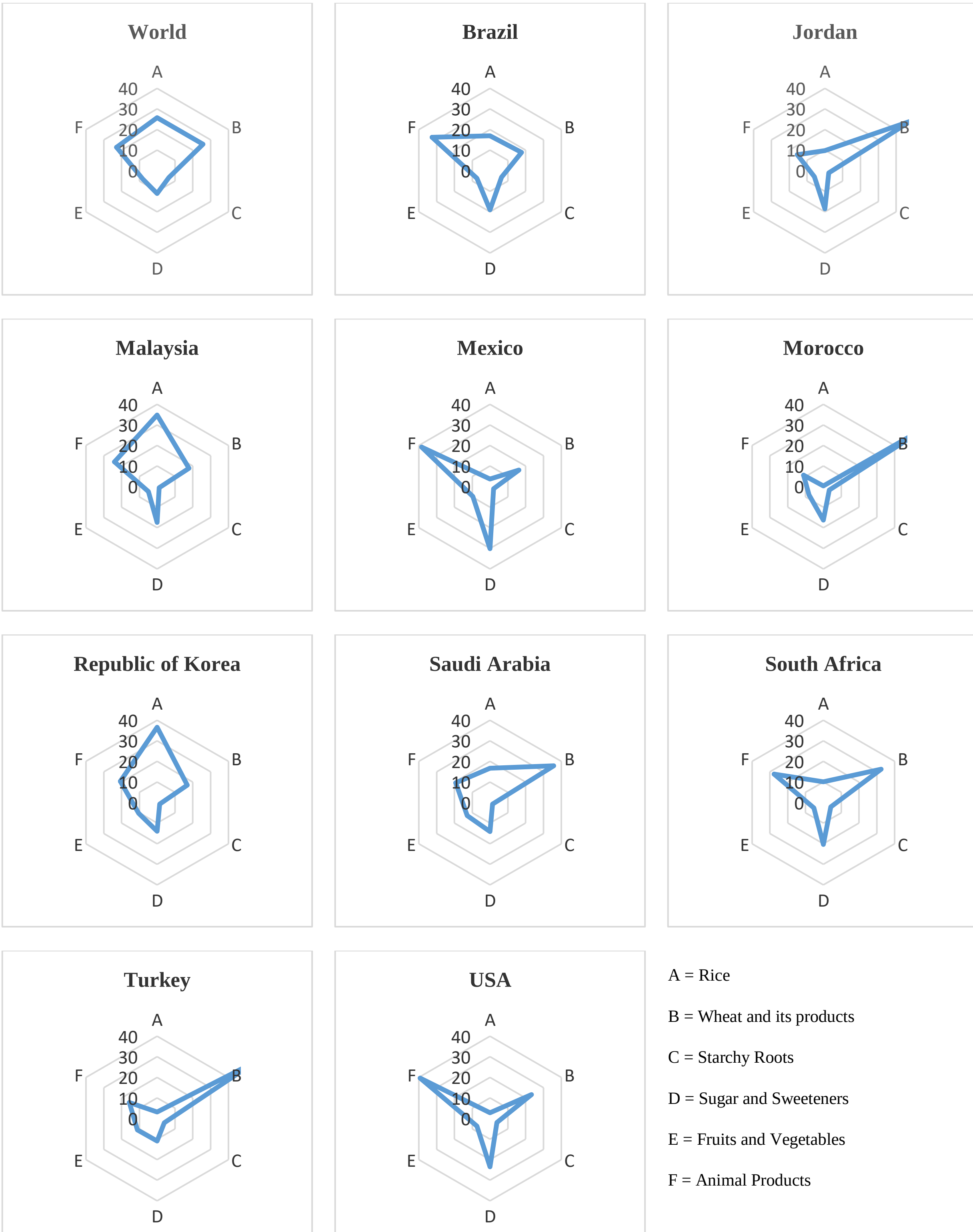

Figure 2.1. Average Distribution of Energy Intake Sources between 2000 and 2011 for Several Countries.

2.8 Analysis Results

The analysis in this chapter goes through two phases. First, I measure dietary diversity on a national level with the food security index, as a previous study suggested, which is also the index for identifying the changes in consumption habits for the 59 countries in this case study. In addition, I look at the association between this index and other multidimensional indices of food security. The results of these analyses are below.

2.8.1 Dietary Diversity Index

Dietary diversity is constructed on three measurements: Simpson Index, Shannon Index, and Quantitative Index of Dietary Diversity, as illustrated in equations 2.1 to 2.4. The values of these indices are between 0 for no diversity and 1 for perfect diversity for six food groups as energy intake sources. I have measured the three indices of dietary diversity by applying them to several countries. In general, the Quantitative Index and Shannon Index, used on nine countries (Brazil, Jordan, Malaysia, Mexico, Morocco, the Republic of Korea, Saudi Arabia, South Africa, and Turkey), show a high level of diversity compared to the Simpson Index for all of the countries, and the comparison almost runs in parallel waves (Figure 2.2).

The dietary diversity measured in three diversity metrics between the nine countries in this figure shows the greatest diversity in the food supplies of Brazil and Saudi Arabia during the period between 2000 and 2011. Conversely, Morocco, Turkey, and Jordan have the lowest diversity in their food supplies in the same period of time, while South Africa, Malaysia, the Republic of Korea, and Mexico rank in the middle. Tracing the changes in the diversity of energy intake sources for each country between 2000 and 2011 (Figure 2.2) shows different situations in this diversity over time. The dietary diversity was stable, with small changes that did not exceed 2%, up or down, in most of the countries in Figure 2.2, including Brazil, Malaysia, Mexico, the Republic of Korea, Saudi Arabia, and South Africa. Jordan had more fluctuation in its dietary diversity index and had the highest measure of diversity in 2004. Morocco and Turkey had low values of dietary diversity indices in 2000, but over time, the index values in these countries had some improvement and they had the highest values in 2011.

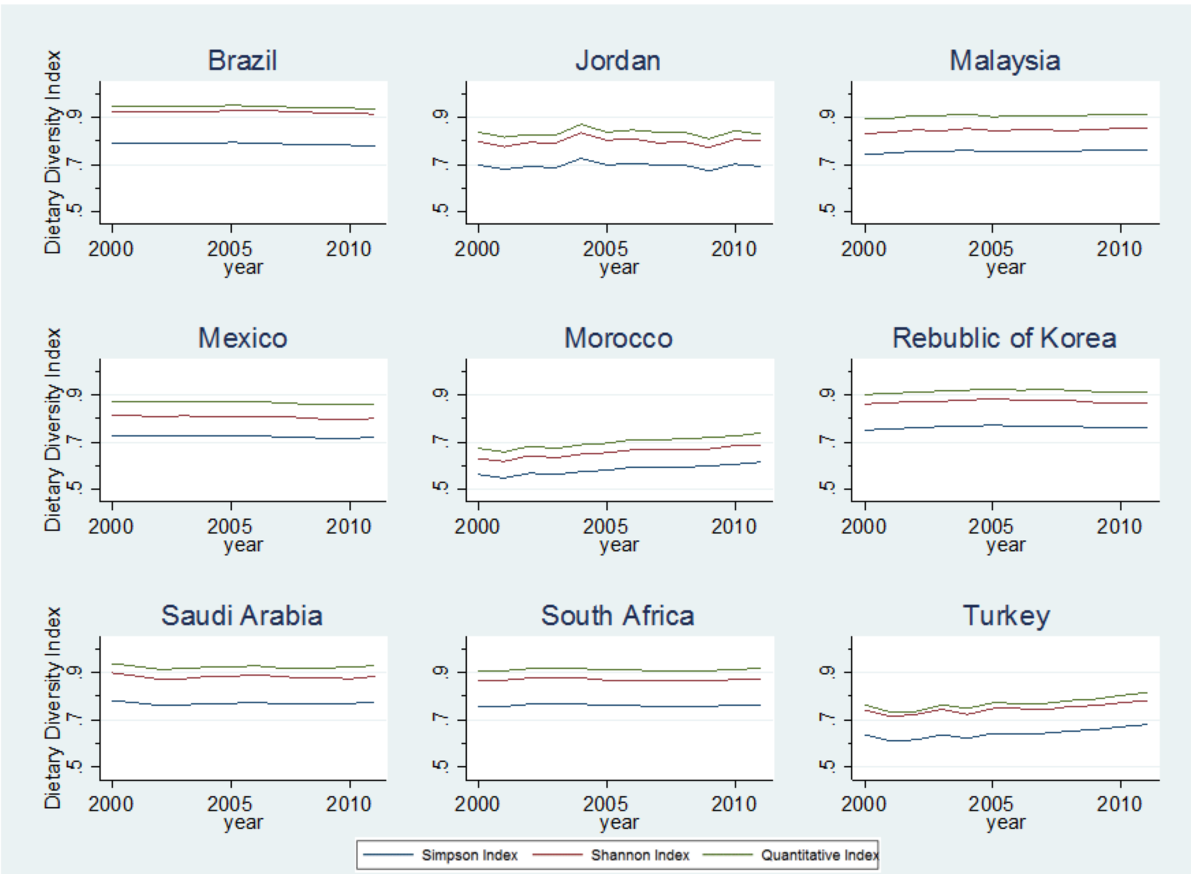

Figure 2.2. Levels of Dietary Diversity in Several Countries Using Three Diversity Metrics (Simpson Index, Shannon Index, and Quantitative Index) between 2000 and 2011.

The ranking of nine countries based on three metrics of dietary diversity shows a relatively similar ranking between countries through the three metrics. The Simpson Index corresponds to the Quantitative Index because the latter metric of dietary diversity is a derivative of the former. In 2011, the ranking of countries, beginning with the best dietary diversity level and using the Simpson and Quantitative indices, was: Brazil, Saudi Arabia, South Africa, Malaysia, the Republic of Korea, Mexico, Jordan, Turkey, and Morocco (Table 2.2). The only countries that have different rankings in the Shannon Index are Malaysia and the Republic of Korea, and they replaced each other's rankings in 2011 because their values of dietary diversity were relatively close.

These indices of dietary diversity may a show high level of diversity on a country level because of the wide variety of preferences for individuals inside a country, and this study used food groups in the construction of the dietary diversity index rather than using individual items. The only items included in the dietary diversity index were rice and wheat products because they are the sources of a large portion of energy intake; they can reach around 50% of the total energy intake for some countries and the world average, as mentioned previously. On the other hand, the reasons for including food groups are represented in the small amounts of consumption for some of the individual items in these groups that contain weak nutritional energy intakes.

Because these three metrics (Shannon Index, Simpson Index, and Quantitative Index) have the same movement to measuring dietary diversity with different values, the comparison between the dietary diversity indices of these metrics will be the same as other food security indices. Morris et al. (2014) also verified the strong correlation between several diversity indices, which included the Shannon and Simpson indices. Thus, one dietary diversity metric is enough to compare to other indices of food security. The Simpson Index is the most preferable metric because it contains the most meaningful and robust measures of diversity, which makes the index heavily weighted for abundant species and less sensitive to species richness (Magurran, 2013). Therefore, the Simpson Index was chosen for reflecting the intensity of the diversity of different energy intake sources and determining the association to other measurements of food security. Furthermore, the small changes in dietary diversity values from year to year, as in Figure 2.2, depend on the average value across countries during the study period (2000–2011) in order to determine dietary diversity's association with other factors, such as the multidimensional food security index.

Table 2.2. Ranking of Dietary Diversity for a Sample of Nine Countries in this Study Compared to Different Metrics in 2011.

	Simpson Index		**Shannon Index**		**Quantitative Index**	
	Value	Rank	Value	Rank	Value	Rank
Brazil	0.78	1	0.92	1	0.98	1
Jordan	0.69	7	0.80	7	0.82	7
Malaysia	0.76	4	0.85	5	0.90	4
Mexico	0.72	6	0.80	6	0.92	6
Morocco	0.61	9	0.69	9	0.71	9
Republic of Korea	0.76	5	0.87	4	0.89	5
Saudi Arabia	0.77	2	0.88	2	0.92	2
South Africa	0.76	3	0.88	3	0.92	3
Turkey	0.68	8	0.78	8	0.80	8

2.8.2 The Relationship Between Dietary Diversity and the Multidimensional Food Security Index

As demonstrated above, the analysis of dietary diversity measures depends on the Simpson Index to measure the diversity and the average value for each country between 2000 and 2011. Table 2.3 shows the rankings of 59 countries based on their values in the dietary diversity index in 2011 and compares them to their rankings in the multidimensional food security index. The top five countries in dietary diversity in 2011 were Peru, Bolivia, Colombia, Oman, and Costa Rica, while Laos, Indonesia, Tunisia, Morocco, and Algeria had the lowest levels of dietary diversity. Most of these countries did not have a correlation between their rankings based on the dietary diversity index and the multidimensional food security index. The top countries (Belgium in the multidimensional food security index and Peru in the dietary diversity index) were not even closely ranked for these two indices. The only countries that had relatively close rankings based on both indices were Jordan, Laos, Morocco, and Pakistan, and all of these countries had low levels of food security compared to the majority of the countries in this study. In conclusion, the comparison of rankings between the dietary diversity index and the multidimensional food security index in the previous chapter for 2011 does not portray a consistency in their rankings. In this section, I use a statistical method to analyze the association between the multidimensional food security index and two food consumption behaviors. The first consumption behavior is the total food consumption, which is measured using the total supply of energy intake in average annual kilocalories per capita per day from all kinds of food groups for each country. The second consumption behavior is the diversity of energy intake sources, called “dietary diversity,” which is measured using six food groups, as mentioned previously, as food security indices from previous studies.

Table 2.3. Ranking of Countries According to the Dietary Diversity Index (DD) and Multidimensional Food Security Index (FS) in 2011.

Country	Ranking		Country	Ranking	
	DD	FS		DD	FS
Algeria	55	47	Lithuania	40	20
Austria	39	4	Malaysia	14	36
Belarus	17	29	Malta	27	10
Belgium	30	1	Mexico	36	37
Bolivia	2	54	Morocco	56	49
Brazil	6	34	Netherlands	22	5
Bulgaria	52	33	Nicaragua	13	52
Canada	18	15	Norway	47	14
Chile	23	35	Oman	4	41
Colombia	3	48	Pakistan	53	55
Costa Rica	5	39	Paraguay	12	42
Czech Republic	37	12	Peru	1	50
Denmark	45	3	Poland	32	21
El Salvador	10	51	Portugal	26	19
Estonia	20	28	Republic of Korea	15	25
Ethiopia	35	58	Moldova	31	44
Finland	54	16	Russia	24	31
France	49	2	Saudi Arabia	7	43
Germany	41	7	Senegal	50	59
Greece	28	18	Slovakia	42	26
Hungary	43	24	South Africa	11	45
India	19	56	Spain	29	13
Indonesia	58	53	Sweden	44	17
Iran	34	40	Switzerland	38	8
Italy	46	9	Tunisia	57	38
Japan	8	30	Turkey	51	27
Jordan	48	46	Ukraine	16	32
Kuwait	9	22	United Kingdom	21	11
Laos	59	57	United States	25	6
Latvia	33	23			

First, the scatterplots below, Figure 2.3 and Figure 2.4, are used to show the strength of the relationship between several indices. In general, the pattern of the data points on Figure 2.3 reveals the strong, positive relationship between the total supplies of energy intake with each food security dimension (availability, accessibility, utility, and stability) and the overall scores of food security. Conversely, Figure 2.4 shows that the values of the dietary diversity index are not related to any food security dimensions or the aggregation score of food security dimensions.

In addition, the Pearson Correlation Coefficient (γ) and the Spearman Rank Order Correlation (ρ) in equations 2.5 and 2.6 numerically summarize the associations between the average scores of the food security index and of the dimensions of food security, and the average total supplies of energy intake and dietary diversity between 2000 and 2011 for 59 countries. The Pearson Correlation Coefficient assumes linearity and a normal distribution of associations between the variables. On the other side, the Spearman Correlation evaluates the monotonic association between the variables and does not assume linearity and normal distribution.

The results of the two correlation measures show the significant and strong association between three of the food security pillars and the kilocalories of energy intake (availability dimension: $\gamma = 0.91$, $\rho = 0.89$; accessibility dimension: $\gamma = 0.77$, $\rho = 0.77$; and utility dimension: $\gamma = 0.83$, $\rho = 0.79$), while the stability dimension has a moderately positive association with kilocalories of energy intake ($\gamma = 0.35$, $\rho = 0.28$). Moreover, the kilocalories of energy intake have a strong positive association with the aggregation of all of these dimensions in the food security index, according to the Pearson and Spearman correlation coefficients ($\gamma = 0.88$, $\rho = 0.86$), and all of these values are significant at 5%. In another measurement made by the correlations, the average scores of the dimensions of food security did not show a significant association with the values of the dietary diversity index across 59 countries using a linear (Pearson) or non-linear (Spearman) correlation (Table 2.4).

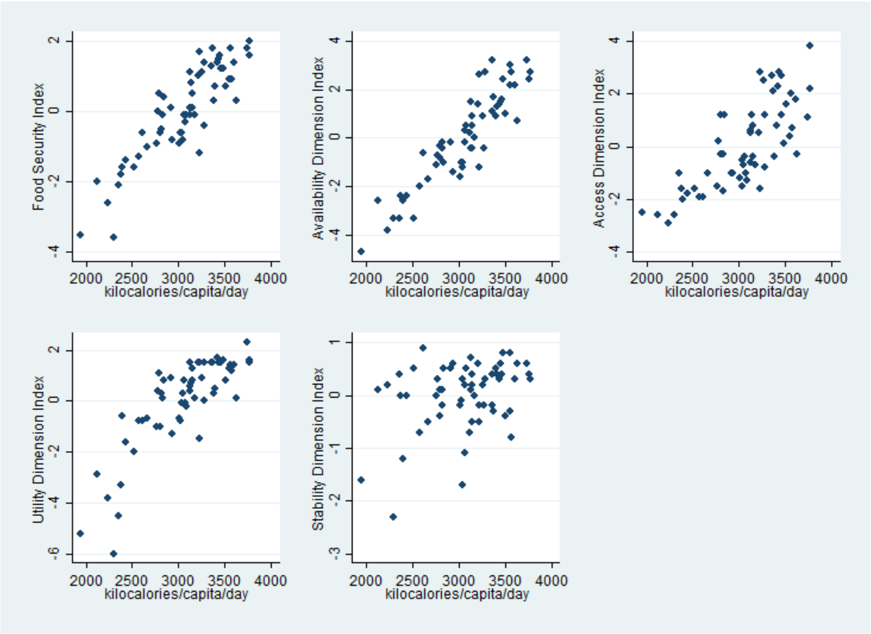

Figure 2.3. Relationship Between the Average Total Supplies of Energy Intake and the Food Security Pillars in 59 Countries (2000–2011).

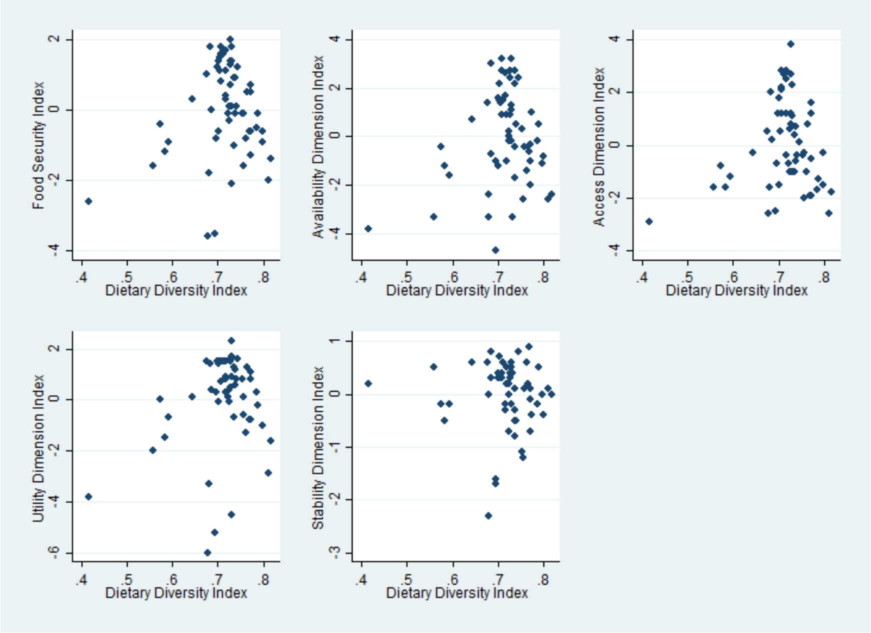

Figure 2.4. Relationship Between the Average Dietary Diversity and the Food Security Pillars in 59 Countries (2000–2011).

Table 2.4. Correlation Coefficients Between Diets in Total and Diversity Scores from the Multi-Dimensional Food Security Index for Several Countries Between 2000 and 2011.

Index	Corr. Test	Availability Dimension	Accessibility Dimension	Utility Dimension	Stability Dimension	Aggregation Score of Food Security
Total Supply of Energy Intake	Pearson	0.91**	0.77**	0.83**	0.35**	0.88**
	Spearman	0.89**	0.77**	0.79**	0.28**	0.86**
Dietary Diversity	Pearson	0.18	0.12	0.22	-0.02	0.18
	Spearman	-0.05	-0.09	-0.05	-0.14	-0.08

** significant at 5%

Table 2.5. OLS Regression for the Impact of Food Security Levels on Diets in Total and Diversity Scores for 59 Countries Between 2000 and 2011.

Index		Availability Dimension	Accessibility Dimension	Utility Dimension	Stability Dimension	Aggregation Score of Food Security
Total Supply of Energy Intake	Intercept	3,053.60**	3,053.96**	3,056.03**	3,055.34**	3,055.34**
	Slope	205.15**.	203.80**	202.56**	239.98**	291.28**
	R-Squared	0.82	0.58	0.68	0.12	0.78
Dietary Diversity	Intercept	0.72**	0.72**	0.72**	0.72**	0.72**
	Slope	0.01	0.004	0.01*	-0.002	0.01
	R-Squared	0.03	0.01	0.05	0.00	0.03

* significant at 10%
** significant at 5%

There are five equations for each total energy intake supply and dietary diversity level, which are used to determine the association between food security dimensions and the aggregate scores of these dimensions by using the regression model (Equation 2.7). The output of the linear regression shows a significant impact of the food security dimensions and the aggregate scores of these dimensions on the total energy intake supply (Table 2.5). For a single dimension, a one-point increase in the scores of availability, accessibility, utility, and stability can lead to an increase in the average total energy intake supply by 205, 203, 202, and 239 kilocalories per capita per day, respectively. All of these values are statistically significant at 5%. In these models, R-Squared can measure a model's performance, in which 82%, 58%, 68%, and 12% of a variation in the energy intake supply can be separately explained by equations from the availability dimension, accessibility dimension, utility dimension, and stability dimension, respectively, according to the regression results. Similarly, the aggregate scores of food security include all four food security pillars in one index, and the results conclude that a one-point change in a score of food security can lead to a change in the average total supply of energy intake by 291 kilocalories per capita per day. A 78% variation in the total supply of energy intake in this equation can be explained by the aggregation of food security dimensions. In the same way, the regression analysis was done for dietary diversity by using the same independent variables in separate equations. Surprisingly, none of the food security dimensions or aggregate indices of these pillars had a significant relationship with food dietary diversity, except for a very small effect of the utility dimension at a 10% level of significance. Likewise, a dietary diversity index increase of 0.01 point can force the utility dimension index to increase by one point.

2.9 Discussion and Recommendations

Dietary diversity is important for nutrient adequacy (Hatloy et al., 1998; Ogle et al., 2001; Mirmiran et al., 2006) and healthy life (Remans et al., 2014). The association of dietary diversity with food security, however, is not verified even though there are several studies that use dietary diversity as indicator of food security (Hoddinott and Yohannes, 2002; Thorne-Lyman et al., 2010). The hypothesis of this study supposed an association between dietary diversity and the multidimensional food security index, but the results of the graphs and correlations conclude that there is no association. In addition, the same results were obtained by using the linear regression method, which led me to reject my study's hypothesis. More in-depth analyses of the impact of the multidimensional food security index on the total supply of energy intake determined that there is a high association for all of the dimensions of food security, except for the stability dimension, which is less related to energy intake.

Therefore, the results of analyzing the data from 59 countries concluded that the improvement of some factors of the multidimensional food security index by decision-makers does not guarantee a change in the consumption habits that create dietary diversity, which is recommended by other studies for increasing food security. On the other side, the results of the study found that another consumption habit — the size of consumption that represents the total supply of energy intake — is associated with the multidimensional food security index. In other words, improving the factors that are included in the multidimensional index of food security from chapter 1, might lead to an improvement of the food supply in a certain country but not necessarily to a larger diversity of food products. According to previous research, there are several factors that could lead to the differences in dietary diversity levels among different societies, such as household sizes, levels of education, food expenditures, wealth, prices of food products, living area (whether urban or rural area), age, gender, BMI, and job status (Rajendran et al., 2014; Hatloy et al., 2000; Brinkman et al., 2010; Regmi et al., 2001; Leatherman, 1994; Clausen et al., 2005; Mirmiranet et al., 2006; Thorne-Lyman et al., 2010).This study does not discuss the reasons for the weak association between the two indices (of dietary diversity and multidimensional food security), which will require more research at this point. In addition, further studies will be required to identify the association between dietary diversity and the factors that have constructed the component food security index, instead of representing these components with indices, to get an accurate result.

2.10 Summary

This chapter addresses one important aspect of food security: dietary diversity. This study assumed that a heterogeneous level of dietary diversity across several countries would be related to their levels of food security. There are several indices that can be used to measure the diversity of food on a countrywide level. This chapter used the Simpson Index to measure the energy intake diversity of six food groups (rice, wheat products, starchy roots, sugars and sweeteners, fruits and vegetables, and animal products) and the multidimensional food security index, constructed in the first chapter, to represent levels of food security. This case study used the average data between 2000 and 2011 for 59 countries. In conclusion, these correlations and linear regression models have found that dietary diversity is not affected by levels of multidimensional food security, while the sizes of energy intake increase with levels of food security.

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Chapter 3: A Descriptive and Qualitative Study of Food Security in Saudi Arabia

3.1 Introduction

Food security is a serious challenge faced by many countries. Economists and researchers from other disciplines are working on indicating and clarifying the problem. Clarifying the problem of food security will help design rational policies that, in turn, could improve food security without too severely affecting other parts of the economy. Food security is a particularly complicated problem in desert countries such as Saudi Arabia that suffer from water scarcity.

The government of Saudi Arabia actively encouraged agricultural production from the 1970's until 2009 in order to enhance food security (Mousa, 2010; Souhail, 2008). The goal was to increase production levels and to achieve self-sufficiency from several crops. On the downside, this policy contributed to reducing water stocks and increasing the country's water shortages after high depletion rate, whereas the agricultural sector is the main reason for this depletion (Lovelle, 2015). This is an example of how dealing with food security increases the need to balance different choices. When analyzing these trade-offs for a given country, the first step is to understand this country's specific circumstances.

The first two chapters offered ideas about the factors that contribute to food security. The goal of this chapter is to apply what we have done in the first two chapters to Saudi Arabia and to examine the changes in the food security index and in other political and economic variables over time. Also, this chapter describes opportunities and challenges for food security in Saudi Arabia's economy and completes the country's food security picture. This chapter will cover the following areas: description and interpretation of food security issues in the country, evaluation of previous policy tools that deal with food security, and proposals of mechanisms that could be used in the future.

3.2 General Information about Saudi Arabia

The official name of the country is the Kingdom of Saudi Arabia. The modern state was founded in 1932. It is located in Southwest of Asia and constitutes about 80% of size of Arabian Peninsula. Saudi Arabia is bounded by Jordan and Iraq in the north; Kuwait in the northeast; the Arabian Gulf, Qatar, and United Arab Emirates in the east; Oman in southeast; Yemen in southwest; and the Red Sea and Gulf of Aqaba in the west, with a total land boundary length of 2.7 thousand miles and 1.6 thousand miles of coastline. The total size of the country is 830 square miles; it is the thirteenth largest country in the world. Saudi Arabia has a diverse topography because it occupies a large area, but the nature of country is dominated by the desert. The country includes large size deserts, of which 250,000 square miles represent Rub'al Khali (or Empty Quarter) in the southern part of the country. Saudi Arabia does not have rivers or lakes. The country is divided into 13 administrative regions and 118 governorates. The population of Saudi Arabia exceeded 31 million in 2015, with more than 33% being temporary residents. 41% of its population is younger than 25 years, as of 2016, which reflects a high rate of population growth; thus, the average annual growth rate in population was 3% in last decade, while 50% of the population is between 25 and 54 years.

The weather in most parts of Saudi Arabia is desert climate; the average temperature in the summer is around 113^{o}F and can reach up to 129^{o}F with dust and sandstorms. The interior regions have higher temperatures than the coastal regions and mountains in the south of the country (Asir region), while the temperature could go below 32^{o}F in the winter. The average annual rainfall in Saudi Arabia is 3.5 in., with higher rate of rainfall in the Asir area between 10 to 20 in.

Saudi Arabia is a high-income country, with its wealth coming from the oil industry; the country owns the largest reserves of petroleum in the world. The total GDP was $646 billion, and the GDP per capita was about $20.5 thousand in 2015, according to the World Bank data. The service and industry sectors provide the large contribution in GDP; the value added from these sectors represents around 52% and 46% of GDP, respectively. The greatest challenge for the future Saudi economy is the diversification in economic productivity sectors.

3.3 Objective of Study

This chapter is about the perspective of enhancement and getting sustainable food security on a national level for Saudi Arabia. Developing food security is not only achieved through self-sufficiency from agricultural production but also by finding a balance for productive potential and natural resources. Thus, this chapter discusses the circumstances of Saudi Arabia having different choices to improve food security, which could be used in any future food security programs or strategies.

3.4 Historical Situation of Food Security in Saudi Arabia

Several previous studies have compared the situation of food security in Saudi Arabia with other countries during different times. Each study uses a different aspect of food security. Thus, it is helpful to review the food security status for Saudi Arabia in regards to each study.

3.4.1 Global Food Security Index

First, the global food security index (GFSI) depends on 28 indicators inside three dimensions: affordability, availability, and quality and safety. The Economist Intelligence Unit (EIU) has evaluated the situation of food security across different countries annually since 2012.

Food security scores for Saudi Arabia according to this index were between 68.9 and 71.1 out of 100 points. The ranking of Saudi Arabia changes from year to year and was between 31 and 34 from 113 countries the GFSI evaluated. The worse score was 68.9 with rank 34 in 2013 for Saudi Arabia. The performances of all three dimensions are between 63 and 77 from 100. The greatest advantage to scores of food security in Saudi Arabia come from the affordability dimension. Indicators of this dimension include share of food consumption from household expenditures, proportion of population under the global poverty line, gross domestic product per capita, agricultural import tariffs, presence of food safety net programs, and access to financing for farmers.

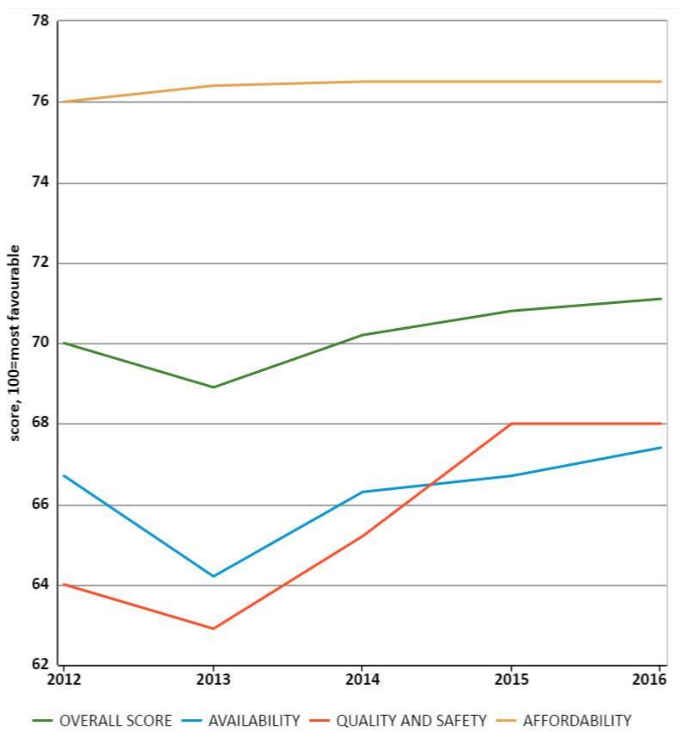

Figure 3.1. Global food security index (GFSI) for Saudi Arabia from 2012–2016.

3.4.2 Global Hunger Index

Food security in Saudi Arabia also is evaluated by the global hunger index (GHI). It is a multidimensional measure from the International Food Policy Research Institute's (IFPRI) annual report since 2006. Proportion of the undernourished in the population, prevalence of underweight in children, and children mortality rate are factors used to construct this index. This index ranked Saudi Arabia as moderate-to-low for hunger during the period of 1981 to 2014, which is the lowest category on IFPRI's hunger scale. According to this index, Saudi Arabia reduced hunger by 62% between 1990 and 2014. In 2015, the IFPRI changed the factors to include analyzing global hunger through four indicators (undernourishment, child wasting, child stunting, and child mortality rate) and calculating GHI index during 1990, 1995, 2000, 2005, and 2015. The GHI scores for Saudi Arabia are still in a moderate to low level via the new hunger index weight. The advantage of this index is that it compares food security in different countries and regions during different period of time by using factors of hunger manifestations. This method offers an indication of the impact of food insecurity on certain aspects of life, but it does discuss the factors (political, economic, and others) that cause changes.

3.4.3 Composite Index of Food Security

Besides these food security measurements in Saudi Arabia, research from the previous chapter also constructed two measurements to look at the change of food security during a period of time. The first measurement is a composite index and dependence on food security pillars (availability, access, utilization, and stability of food). I am using the percentage change in the value for aggregation scores for all dimensions and the scores for each dimension to look at the change in food security levels because the actual value compares the improvement in food security level. According to the aggregation score of the multiple-dimensions index, the food security index shows a 21% improvement between 2000 and 2011; thus, this index matches the results from other studies in regards to the improvement of food security. This index decreased over several years (2003, 2004, and 2005) compared with previous years, while it has some improvement in other years. Most decreases of this index stems from reduction of the index score of availability with stability dimensions.

The change in index of food security pillars (available, access, utilization, and stability) for Saudi Arabia varies during study time (2000–2011). For the availability dimension, there was a negative change between 2002 to 2009, which is due to the change in the Saudi government's policy to move from domestic production of food to obtaining food from the global market. Thus, the new policy did not only reduce the production value compared with that of other countries but also reduced the average supply of energy and protein from different resources, which are indicators of the availability dimension. Values of the availability index show some improvement in last two years of study time, which could be explained by the increase in average supply of energy and protein by the increase of food imports. The food access dimension has a positive effect on the final score of food security for the time between 2000–2011. This index increased by 18.5% from 2000 to 2011. The reasons for this improvement is the growth of gross domestic product (GDP) in Saudi Arabia from oil revenue, while there is almost a steady change in other indicators of physical access. The small negative change occurring in this pillar of food security in some years (2002, 2003, and 2006) may refer to inflation in domestic food prices, even in the subsidies paid by the government to support food price stability in Saudi Arabia. The food utilization index score increased in Saudi Arabia during the study period between 4% to 8% each year. The positive change in this pillar of food security reflects the improvement of infrastructure and health development in the country, which are represented here by improving water resources and sanitation facilities in the infrastructure side, and reducing the anemia for women and children in the health side. The last dimension of food security is stability; the value of this dimension shows a high fluctuation in Saudi Arabia. This fluctuation refers to variability in food supply and food production.

Table 3.1. Annual Percentage Change in the Food Security Index and Its Dimensions for Saudi Arabia between (2000–2011).

Level of Food Security	△2001	△2002	△2003	△2004	△2005	△2006	△2007	△2008	△2009	△2010	△2011	Δ (2000-2011)
Aggregation index	4.56	5.94	-1.44	-4.46	-6.99	5.38	9.80	2.65	0.01	1.21	4.39	21
Availability	3.04	-7.50	-8.91	-11.68	-0.47	-3.04	-2.94	-8.81	-3.41	11.66	3.04	-6.3
Access	25.71	-1.22	-2.33	5.02	3.35	-9.83	0.78	4.28	5.11	0.94	1.92	18.5
Utilization	8.35	5.58	5.58	6.01	6.18	5.17	4.06	5.43	5.35	4.40	3.80	60
Stability	8.08	28.00	-7.45	-15.51	-23.86	18.63	33.81	8.88	-2.84	-13.17	-22.46	12

3.4.4 Dietary Diversity Index in Saudi Arabia

Although dietary diversity is not sufficient enough to understand all aspects and the whole situation of food security in any country, as pointed out in the conclusion of the previous chapter, it could offer an indication of patterns for food consumption. Several methods could be used to measure dietary diversity even for households or the country level. In this case study, three methods are used to analyze dietary diversity in Saudi Arabia during 1961–2011, whereas the data available are from the Food and Agriculture Organization (FAO). The three methods are (1) Simpson index, (2) Shannon index, and (3) quantitative index of dietary diversity (QUANTIDD); the equations of these indexes are shown in the previous chapter (Shannon, 1948; Simpson, 1949; Katanoda et al., 2006). All indexes rank dietary diversity from 1, which means equal consumption of all food groups, to 0, which means the country only consumes one type of food. The indexes are calculated by using an annual average supply of different food groups in kilo calories per capita each day in Saudi Arabia. Thus, the construction of these indices depends on six groups of food: rice, wheat and its products, fruits and vegetables, sugar and sweeteners, starchy roots product, and animal products; the energy intake from these groups represent 73% of total supply of energy intake in Saudi Arabia, as shown in Table 2.1.

The dietary diversity analysis for Saudi Arabia shows the same pattern for dietary diversity in the country using different measures; even the values of dietary diversity index have variation between them. The quantitative index of dietary diversity (QUANTIDD) gives the highest values compared with other indexes, followed by the Shannon index, and smaller values for the Simpson index. The dietary diversity index was stable in the study period (1961–2011) with a small positive change between 3.4% for the Simpson and QUANTIDD indexes and 7% for the Shannon index. All three indices dropped the most in 1991, with a decrease of around 4% compared to the year before. Supplies of all commodity groups decreased compared with five years ago except for wheat and starchy roots products groups. The reason for the decrease in supplies for several commodities is the 1990–1991 Gulf War. Accordingly, the dietary diversity index has the ability to reflect the events and action that affect food security status.

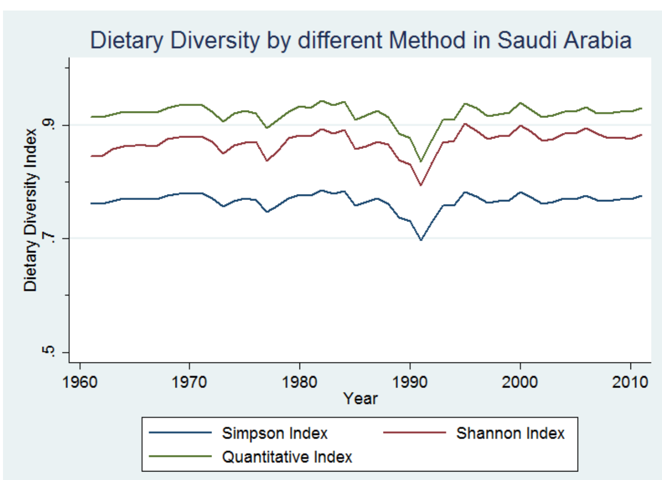

Figure 3.2. Dietary Diversity by Different Methods in Saudi Arabia between 1961–2011.

3.5 Food Security from the Perspective of National Development Planning

The government of Saudi Arabia is concerned about food security because the country suffers from limited water resources. Research regarding changes in food security should evaluate the efforts to develop the domestic agricultural sector to provide secure food. The Saudi government is focused on improving infrastructure for food production and easy access to domestic and international food for the Saudi market. In addition, it also works to ease access for consumers to food products by subsidizing agriculture domestic production and imported food. Here, I will review the approach of country's governments to deal with food security problems and the change of actions and policies during different perspectives to enhance food security since 1970 (Development Plan, 1970–2010). The improvement of food security in Saudi Arabia has gone through several stages, and government policies have the primary effect to change through positive or negative factors, which could have an impact on the level of food security in the country.

In general, the responsibility to achieve agricultural development and to meet the requirements of food security in Saudi Arabia is shared by several institutions such as the Agriculture Ministry, Agricultural Development Fund, and Saudi Grains Organization. The contribution of the Agricultural Ministry is represented in the design and implementation of agricultural and food policies for the government. The mission of the Agricultural Development Fund is represented in the support of agricultural development, which is subject to the government's vision through presenting loans and subsidies for food and agricultural projects. Finally, the mission of Saudi Grains Organization is to buy grain crops from domestic and international producers, maintain a strategic stock of grain for six months, and provide subsidies from the government to domestic producers and consumers by support the grain products prices such as wheat and barley.

This review will cover five-year development plans by tracking the progress of food security policies from one period to other one. The government of Saudi Arabia has thus far issued 10 development plans since 1970. It gives the prospective of several sectors (for example, agriculture, natural resources, education, industry, and oil) and challenges to meet the goals. The review is divided into three periods, and each period involves three versions of the five-year development plan, which includes the first period from 1970–1985, second period between 1985–2000, and third period between 2000–2015. Each period has special characteristics utilizing different methods to achieve food security.

3.5.1 First Stage (1970–1985)

The first, second, and third plans of development are involved in this stage between 1970 and 1985. Information from the beginning of this stage is not extensive, and most data consists of approximate and inaccurate values. The government in this period encouraged agricultural production to reduce the gaps of food needs, but the desert nature of Saudi Arabia and water scarcity remained a significant challenge for decision-makers. For that, the government embarked on several projects to get the water such as drilling, establishment of sea water desalination plants, and dams to meet water needs for residential, industrial, and agricultural sectors. In general, the goals of this stage included improvement in the percentage of self-sufficiency for different crops and food products.

The first development plan in 1970 did not offer more details about the food and agricultural sector, but it targeted growth in the agricultural sector to meet food consumption, while the second development plan in 1975 was unsure about the abundance of underground water; it was recommended to do more research. The third development plan in 1980 confirmed the high quantities of water stored underground; thus, underground water could be enough for 100 years without any shortage in water demand for housing, industry, and agricultural uses. However, for several reasons, this idea turned out to be misguided.

There were limitations to using new technology and fertilizers in agricultural production when this phase began. Also, the average farm size was small. Accordingly, the productivity was weak with low quantities of food production size. Therefore, the government provided more loans in this stage to agricultural projects; thus, farmers borrowed more than $1 billion from the Agricultural Development Fund at the end of this stage (unless explicitly stated, all dollar amounts in this chapter are nominal). In addition, loans and subsidies were provided from the Agricultural Ministry in order to obtain new technologies in agricultural projects such as dairy and poultry farms and crop production.

At the end of this stage, investors in the agricultural and food sectors obtained benefits from infrastructures that were established by the government, such as agricultural institutions, road networks to connect production regions by market and consumption regions, and increase subsidy and loan values from financial institutions. Therefore, many investors founded specialized enterprises in poultry production, dairy farms, greenhouse farms, and livestock farms. Funds for agricultural production came not only from the government, but also private banks participated, with around 21% from loan values between 1980 and 1985. In 1981, the government founded two commercial corporations (Nadec and Alasmak) to contribute to food security, in which the government fund shares ownership with other investors. Presently, Nadec is one main food company in the Saudi market, and the government fund still owns 20% of it. This company owns several enterprises in crops production, dairy farms, and food industries.

Also, the government contributed to establish Alasmak, which is a Saudi fisheries company— a government fund owns 40% of this company. The other way to induce agricultural development is the distribution of public lands for free to establish agricultural projects. In 1985, the government distributed more than 700,000 acres, whereas 10 agricultural shareholding companies obtained 34% of them, and the other 40% to fund 1,456 specialized enterprises.

The government also supported prices of main food products in this stage in order to reduce price fluctuations. Thus, the government institutions paid subsidies for producers and suppliers of food products such as the subsidies for wheat producers, whereas the Saudi Grains Organization started in 1979 to buy wheat crops from producers at $933 per ton, when the world price was between $350–$500 per ton.

After all this support from the government of Saudi Arabia and the interest of investment in agricultural and food enterprise from the private sector, the growth in food production reached the highest rate. The growth of wheat crops increased ninefold between 1970 to 1985, and the country gained self-sufficiency. Also, poultry meat growth was 300% with other increases in the production of eggs, fresh dairy products, vegetables, dates, and fruit. Therefore, the country achieved a high level of self-sufficiency for several food products.

The annual growth in value added by the agricultural sector, according to World Bank data, moved from 3.9% during the 1971 to 54% in 1978 and 18% in 1985. At the same time, the challenge in this stage represented an increase in food consumption as a result of income increase, growth of population in the country, and the change of consumption patterns. The increase of food consumption occurred for several food products such as eggs, poultry, fresh fruit, dairy product, meat, and fish. The value of domestic food was 55% of the total value of all food consumption, while the other 45% was imported. During the 1970s, the value of food imports increased by 13% compared with the 1960s.

3.5.2 Second Stage (1985–2000)

To reach a high level of self-sufficiency from domestic agricultural production was the main target to achieve food security in the second stage as it was in the first stage, but concerns began to arise about water consumption from nonrenewable water sources. The first stage did not show much concern about water scarcity, which was reflected by several policies to encourage development in agricultural sector. The consumption of water increased by 84% between 1985 and 1990, four times more than expected in the development plan. The other concern in agricultural development was the concentration of wheat production, which ignored the diversity of production. Therefore, the government began to review food and agricultural policies and work on compatibility between contradictory goals (food security and prevention of water scarcity). The three development plans between 1985 and 2000 confirmed this and emphasized a national strategy to manage and develop water resources along with review of previous policies. Therefore, new policies were targeted to encourage food and agricultural enterprises to adopt methods that are more efficient in water usage. Also, the other new policy targets the transformation from producing crops that consume more water to other crops that consume less without any change in target growth in the agricultural sector.

Examples of these policies represent an urge in farmers to reduce water usage by using modern irrigation techniques such as drip irrigation and greenhouses. Also, subsidies for crops that consume more water were reviewed. In addition, the price of buying wheat per metric ton by the Grains Organization reduced from $933 to $533 in 1985 for individual private farms and $390 for agricultural companies, while wheat prices in the world market were between $280 and

$360 in the same year. The new prices led farmers to produce other crops that use less water and decrease wheat yields by 3.8% between 1985 and 1990. In 2000, the decrease in wheat yield was 30% and 75% for barley yield, with an increase in yield from other agricultural enterprises. Thus, the diversity of food production was wider in response to domestic demand from food products at the end of this stage.

The Saudi government kept some policies, such as the distribution of public lands for free and interest-free loans, for agricultural enterprises. Also, private sectors still preferred the investment in food and agricultural projects, which led to achieve growth in crops yield, livestock, and fish, with an increase in production efficiency. Therefore, the production cost decreases for some crops such wheat and barley, which increases yield. Some food products became more self-sufficient such as wheat (115%) and eggs (118%), while some other foods had a good standing of becoming self-sufficient such as meat (75%), poultry (72%), and fresh milk (73%) in 1988. In addition, the value added from the agricultural sector in GDP reached a maximum level between 1988 and 2000, which was between 4.9% and 6.3% of GDP.

The other major policy related to food security in this time period represented in the expansion of storage capacity for grains from 955,000 metric tons to 1.8 million metric tons, then 2.4 million metric tons to storage the crops yields, which is enough for consumption in next six months and to support the feed industry. Also, the Grains Organization imported 3.5 million metric tons of barley in the annual average between 1986 and 2000 to cover the domestic consumption and distributed it by subsidy price.

3.5.3 Third Stage (2000–2015)

The agricultural sector attempted to maintain annual growth during the time period between 2000 and 2015 and was concerned with the imperfection of food security systems due to the consumption of a lot of water in food production, while the country suffered from water scarcity. In this stage, the government of Saudi Arabia continued the review of some policies such as subsidy systems and distribution of public lands.

Thus, the government decided in 2003 to reduce the price of buying wheat from farmers from $533 to $260 per ton, applied in 2005, while the world price in the same year was between $300 to $600 per ton. Not only that, but the Saudi government determined the quantity to buy from each agricultural company, which was no more than 600,000 tons per year. In 2007, the government decided to give up idea of becoming self-sufficient for wheat crops, which began three decades ago. The new policy was targeted to quit domestic production of wheat by 2016 by reducing 12.5% each year of wheat yield purchased from the domestic market. The gap of domestic demand is planned to be covered by the Saudi Grains Organization through imports from the world market, which started in 2009 to import 1.91 million metric tons from wheat yields beside the 946,000 tons from domestic production. Through this regulation, the government promises to bear any tariff for agricultural products such as wheat or feedstuff and to prevent the export of wheat or feedstuff products at the same time. The other new regulation in this period of time that affected the food and agricultural sector is the pause of public land distribution in 2003 for five years; the government extended it for other five years in 2007. The government still provided interest-free loans to farmers through the Saudi Agricultural Fund, with annual loans for this fund between $195 – $286 million between 2000 and 2015. Subsidies for farmers were reduced over time, which was around $360 million (2001–2005), $200 million (2006–2010), and $130 million (2011–2015).

The Saudi Arabian government's new project related to food security in this stage was the initiative of agricultural investment abroad. The initiative launched in January 2009 to make up the shortage in global production after the global food crisis in 2007–2008, and as a result the decrease in domestic crops production was compensated by an increase in food imports. The initiative target to provide political and financial support for Saudi Arabia's private sector to invest in abroad agricultural enterprises was budgeted at around $800 million.

Even though all these policies were adopted by the government, the agricultural sector still grew during this stage, except in 2010. The annual growth value added from the agriculture sector according to World Bank statistics in Saudi Arabia was 0.6% (2001), 1.1% (2005), -1% (2010), and 1.1% (2015). The crops acreage had an annual decrease at the same time, which reduced from 1,024,000 acreages (2002) to 700,000 acreages (2013). Specifically, the acreage grains and feedstuff reduced by 75% and 7%, respectively in 2013 compared with acreages in 2002, according the annual statistical book by the Ministry of Agriculture (1961–2014).

Overall, looking at these three stages illustrates that food security polices of Saudi Arabia's government had seen an adjustment since 1971. Policy-making began with targets to be more dependent on domestic agricultural production and was motivated to reach more than self-sufficiency for some agricultural food products in some period of time. This growth in domestic production did not take into account the production possibilities frontier subject to the scarcity of available natural resources. The policies of food security change over time with concerns about water resources, and support is reduced to target domestic production until the government desires to end production of some crops that previously received support by policies such as wheat crops. The changes in agricultural and food policies between 1971 and 2015 are summarized in Table 3.2.

Because of government policies in different stages, most factors in the dimensions of food security (availability, access, utility, stability dimensions) improved over time. The only exceptions were factors related to the availability dimension in the third stage. The value of the availability dimension index declined in the third stage, as mentioned earlier (see Table 3.1), because of the policies that were triggered by a concern about increasing water scarcity.

Table 3.2. Summary of Changes in Agricultural and Food Policies between 1971 and 2015.

Year	Theme	Policies for Agricultural Production	Policies for Food Access
1971 – 1985	Improve self-sufficiency through increase of domestic food production.	Provide interest-free loans for any producers or project, distribution of public lands for free, more drilling, and establish dams to meet needs of water, contribution to establish some agricultural companies, and provide subsidies for agricultural production projects.	Establish the infrastructures that create easy access to food such as road and grain storage, and subsidies for final food products' prices.
1985 – 2000	Improve self-sufficiency with concerns about water scarcity, diversity of production, and encouragement to improve productivity.	Encourage the food and agricultural enterprise by interest-free loans to adopt methods that are more efficient in water uses, review the subsidies regulation for crops that consume more water to produce crops that consume less water without any change in target growth in agricultural sector	Expansion of storage capacity for grains to meet the growth in population, and still provide subsidies for final food products' prices.
2000 – 2015	Give up self-sufficiency from some crops because of water scarcity.	Hold the distribution of public lands. Reduce the price of wheat products in the first period of this stage and make a plan to quit crop production in the end of the stage, still provide the interest free loans, and encourage private sector for foreign agricultural investment.	More reliance on imports to meet the domestic demand of food products, government bears any tariffs for some agricultural products such as wheat and reduce the tariffs for other food products, government bears any increase in prices during global food crises, and more expansion of storage capacity for grains.

Table 3.3. Variation of Some Crops Production in Saudi Arabia since 1971.

Crops	Wheat			Barley			Vegetables			Fruits			Green Feed			Total		
	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield
	Thousand Acres	Thousand Ton	Ton per Acres	Thousand Acres	Thousand Ton	Ton per Acres	Thousand Acres	Thousand Ton	Ton per Acres	Thousand Acres	Thousand Ton	Ton per Acres	Thousand Acres	Thousand Ton	Ton per Acres	Thousand Acres	Thousand Ton	Ton per Acres
1971	74	42	0.6	24.7	9	0.4	84	683	8.1	106.2	362	3.4	101.3	493	4.9	1035.4	1718	1.7
1975	153.2	132	0.9	17.3	17	1.0	138.4	884	6.4	158.2	458	2.9	111.2	322	2.9	1262.7	1953	1.5
1980	165.6	142	0.9	9.9	5	0.5	131	756	5.8	177.9	470	2.6	71.7	388	5.4	1504.9	1882	1.3
1985	1450.5	2135	1.5	4.9	4	0.8	229.8	1443	6.3	185.3	687	3.7	358.3	2134	6.0	2337.6	6454	2.8
1990	1905.2	3580	1.9	138.4	372	2.7	269.3	1901	7.1	224.9	804	3.6	496.6	2106	4.2	3407.6	8948	2.6
1995	911.8	1648	1.8	358.3	794	2.2	392.9	2693	6.9	321.2	1053	3.3	753.7	3069	4.1	3217.3	9485	2.9
2000	1035.4	1788	1.7	64.2	118	1.8	232.3	1927	8.3	476.9	1188	2.5	528.8	3263	6.2	2767.6	8550	3.1
2005	1208.3	2648	2.2	17.3	47	2.7	284.2	2571	9.0	536.2	1554	2.9	353.4	2463	7.0	2735.5	9592	3.5
2010	543.6	1349	2.5	4.9	16	3.3	269.3	2521	9.4	558.4	1549	2.8	454.7	3603	7.9	1994	9244	4.6
2013	254.5	660	2.6	4.9	11	2.2	261.9	2729	10.4	560.9	1688	3.0	484.3	3977	8.2	1717.4	9277	5.4

Source: Annual Statistic Book of Agricultural Ministry (1961–2014), Saudi Arabia.

Next is the review of variation in domestic agricultural production for four decades to obtain evidence of the impact of change in government policies toward food security. Table 3.3 illustrates the variation of some crop production in Saudi Arabia between 1971 and 2013. This table keeps track of the change in area size, production size, and yield for wheat, barley, vegetables, fruits, and green feed for each five years period to make it simple to compare their change over time. The change in the values of this table could reflect the direction change for policies that relate to agricultural and food security by Saudi's governments over time. Therefore, the table summarizes the previous three stages of the agricultural sector. The area and production sizes had smaller values in 1971; then they began to grow over time until 1990 for all crops presented in Table 3.3 as a result of adopting policies to obtain self-sufficiency without any concern of other issues such as the scarcity of water resources. The large size of land used in agricultural production was in 1993 and 1994. The higher increase in production through this time was in wheat and barley crops because some government programs focused on these crops as established by the Grains Organization and subsidy prices for these products. The next 15 years saw fluctuations, whereas some crops arrived to peak production size between 1990 and 2005, such as grains products. In 2005, wheat crops production decreased by 35%, and the drop of barley crop production was about 87% compared with sizes in 1990. The decrease in agricultural production refers to the change in government policy to encourage and support domestic production. While there was still improvement in production size of vegetables, fruit, and green feed crops, they were less than the increasing rate in the first period. The same scenario continued between 2005 and 2013 but with different rates of change in production. The grains products have a bigger decrease, which was about 75%, because of government plans to stop domestic wheat production in 2016. As a result of encouragement to use new technology to raise efficiency in growing domestic agricultural projects, the productivity of production increases for all crops through this time.

3.6 Diagnostic of Current Situation

Every country has its considerations and concerns in regards to achieving food security and improving it through time by developing factors of four security dimensions, which are subject to changes in domestic and world circumstances. The primary goal for governments is to guarantee food access for all individuals with affordable prices and enough quantity through time. Identifying the circumstances for each individual country will be helpful to determine optimal choices to any policy related to food security. For example, countries are classified with different levels of food production, depending on their circumstances and possible productivity. Providing the food needs domestically by a country less qualified in its environmental and natural circumstances for production will lead to more deficits in food security in the future and contradictory policies. From this prospective, it is important to identify Saudi Arabia’s circumstances for it to obtain more policy stability toward food security. The three decades between 1980 and 2010 saw a large shift in food security policy in Saudi Arabia from enhancement of domestic food production toward providing food from the world market, as is shown in the previous section.

Therefore, this part of the research studies the challenges, comparative advantages, and recent policies that are related to the enhancement of food security in Saudi Arabia. The political instability in the Middle East, water scarcity, growing reliance on imports for food products, inflation of food product prices, food consumption habits, and population growth rate are the elements that represent the challenges of obtaining food security in the country. On the other side, a high level of GDP in Saudi Arabia is the advantage, which could contribute to overcome the difficulties in obtaining food security.

3.6.1 The Challenges

3.6.1.1 Political instability in the Middle East

Political stability in Saudi Arabia and other countries in Arabic Gulf Cooperation Council (GCC) is enough to protect food security in Saudi Arabia, but it needs political stability in the region and some other countries to be stronger. Since the Gulf war 1990-91, the change of political or economic situations in any part of the world may have an impact on the quantity and prices of food commodities. For example, adopting new energy policies such as using biofuels may have an impact on food availability and food prices. The stability of political and economic situations become more important; when countries with nonstable situations are neighbors, they may still be dependent on each other to produce and transport food. There is nonstability in some Arabic regions, whereas there is the spread of civil war and hunger such as in Syria, Iraq, Yemen, Palestine, Libya, and Sudan. The stability of these countries may impact food security in Saudi Arabia; some of which may be the source of imported food crops to the country, whereas these countries have production constituents for agricultural products such soil fertility, water availability, and labor.

Syria is an example of the effect of nonstability of one country on the food security of Saudi Arabia. Syria exported products to Saudi Arabia, especially agricultural and food products such as live animal and vegetables. Table 3.4 illustrates the impact of civil war in Syria on the import quantity to Saudi Arabia. The total quantity of all products imported from Syria decreased during the civil war to become 42% in 2013 of the original quantity in 2004. Specifically, I am taking tomatoes to see the impact on flow of food products to Saudi Arabia. The quantity of tomato products decreased to be only 11% in 2013 of the original quantity in 2004. Unfortunately, these numbers continued to decrease in last three years.

Table 3.4. Change in Imports to Saudi Arabia from Syria in Total Size of all Products and Tomato during 2004–2013.

Year	Total Import (in 1000 tons)	Change in Total Import (2004 = 100)	Tomato Import (in 1000 tons)	Change in Tomato Import (2004 = 100)
2004	459	100	181.2	100
2005	512	112	188.1	104
2006	494	108	190.9	105
2007	497	108	182	100
2008	452	98	166.148	92
2009	452	98	184.8	102
2010	501	109	178.3	98
2011	539	117	157.6	87
2012	457	100	136.1	75
2013	194	42	19.9	11

In addition, the stability of these counties in the Arabic region is important to food security in Saudi Arabia, according the passage of goods in general and food commodities specifically. The political stability in the region will keep the land transportation of food commodities going and safe from Turkey and Europe countries (Calì et al., 2015; Hande, 2015). For example, the Syrian crisis has stopped all land transportation from these counties to Saudi Arabia. In addition, the stability of countries in the region will help maintain safe shipping traffic, which the sea shipping to Saudi Arabia is going through at least one of three sea straits in the region (Suez Canal, Strait of Bab Al Mandab, and Strait of Hurmuz). The relative importance of seaports in Saudi Arabia from all others ports for commercial products were 81% to 87%

during the period from 2004 and 2013 (Ministry of Economy and Planning, 2004–2013). Therefore, the stability of the countries in the region is one factor that could enhance Saudi Arabia's food security.

3.6.1.2 Water scarcity and domestic agriculture production

The scant availability of water resources and increasing usage of nonrenewable water are significant factors that add pressure to improve food security in Saudi Arabia. Water resources in the country are represented in limited internal renewable and nonrenewable freshwater, rain water, seawater desalination, and wastewater treatment. According to World Bank data, the total of renewable internal freshwater resources in Saudi Arabia was 2.4 billion cubic meters in 2007, while the total annual freshwater withdrawals was 18.08 billion cubic meters in the same year (Table 3.5). This means the percentage of annual freshwater withdrawn is 753% of internal freshwater resources, whereas the withdrawal quantity of water exceeded the availability of renewable consumption from nonrenewable internal resources. The Saudi government has made efforts to develop water resources through the establishment of 482 dams with 2 billion cubic meters' capacity and drilling 8 thousand wells until 2014 (Ministry of Water and Electricity, 2014). Also, the government gave around 145,000 permissions for the private sector to drill wells over 60 years, which means that around 90% of agricultural practices use wells (General Authority of Statistic, 2015).

In fact, most water usage was in the agricultural sectors, which was 85% of total freshwater withdrawal in 2007. This high percentage of freshwater usage in agricultural practices could be understood by knowing that the Saudi government had a program to motivate agricultural productions, which led to push production and consumed more water. Later, the government adopted a new policy in 2007 to reduce water usage in the agricultural sector by depending on the global market instead of domestic production to buy wheat products, which is shown previously in the review of food security in the national development planning section. Unfortunately, data of freshwater use in the agricultural sector in 2014 show that a high percentage of freshwater is still used in the agricultural sector, which represents 84% compares with use in other sectors (industry and home). The change in policy lead some agricultural producers to produce alfalfa, which has a higher price in the domestic market, but it still consumes more water.

Table 3.5. Sizes of Renewable Internal Freshwater Resources and Freshwater Withdrawals in Different Sectors in Saudi Arabia.

	2007	2014
Renewable internal freshwater resources, total (billion cubic meters)	2.4*	2.4*
Annual freshwater withdrawals, total (billion cubic meters)	18.08**	23.42**
Annual freshwater withdrawals, total (% of internal resources)	753**	976**
Annual freshwater withdrawals, agriculture (% of total freshwater withdrawal)	85.28**	83.76**
Annual freshwater withdrawals, industry (% of total freshwater withdrawal)	3.78**	3.97**
Annual freshwater withdrawals, home (% of total freshwater withdrawal)	10.40**	12.27**

Sources. *The World Bank and **Annual Report of Ministry of Water and Electricity (2014).

However, awareness of water scarcity challenges and dealing with them, which are subject to available resources and surrounding circumstances, will help improve food security. Dealing with this challenge could be through sustainable management for available water resources and determining food products that have less consumption of water, which could be targeted for domestic production. The update of some policies is important for the management of water usage, which includes the absence of fees or taxes on water for agricultural usage to discourage waste in the agricultural sector and to encourage farmers to use the water in efficient ways as one of the production inputs.

3.6.1.3 Growing reliance on imports for food products

There are two ways to get the food needs at a national level, even from domestic production or commercial food imports. The Saudi development in early 1973 induced domestic agricultural production to guarantee obtaining food supplies and reducing the exposure for price and quantity fluctuation in global market. Food security in Saudi Arabia in that time was only related to self-sufficiency. Therefore, the Saudi government devised a package of incentives for domestic producers such as subsidies and free loans and land. This policy contributed to increasing food production for several food commodities such as wheat, which had a self-sufficiency rate of more than 100%. Unfortunately, this policy did not consider other aspects such as the sustainability of domestic natural resources. The water scarcity and continuing increases in demand for food as a result of the growth in population and income represent the challenge to keep the same policy for domestic production. Therefore, the decision-makers look at other choices to maintain balance to provide food needs in the domestic market and preserve natural resources. The other choice is the reliance on imports to meet food needs; the reliance on food import is not bad by itself, but more exposure in the world market in price and quantity is a risk, which may lead to sharp rises in food product prices or a shortage in food quantities.

Tables 3.6 and 3.7 show the change in total values and quantity of importing food products in Saudi Arabia. The numbers in these tables offer evidence of the growing reliance on imports for food products to provide food needs in the country. The import values of the food products table present the increase in import values through time from animal and crops (Table 3.6). The import values of food products took 20 years to duplicate the import values (1985 to

2005), while it only took 10 years to duplicate the value of animal products one time and duplicate crops products two times. The increase in crops products' value increases in animal product values through time because of changes in policies for depending on domestic production of wheat in 2007 and increase the imports from this product aside from rice and barley crops. Because of inflation using nominal values to compare food product imports over time is biased; Table 3.7 considers the quantity as a base to follow the change in food product imports rather than its values. The change in quantity of importing food products to Saudi Arabia include any food, whether animal or crops products, between 2005 and 2014, for which the data were not available before this time. The conclusion of Table 3.7 is that the growth of food imports to provide food needs in Saudi Arabia has not changed. The only change was the percentage of increase, which was 86% in 2014 compared to 2005. The percentage change in food imports by quantity was less than the percentage change in food imports by value because of inflation rate, as previously mentioned.

Table 3.6. Change in Total Values of Importing Food Products to Saudi Arabia since 1985.

Year	Animal Products Values (Million Dollars)	Change in Animal Products Values (2005 = 100)	Crops Products Values (Million Dollars)	Change in Crops Products Values (2005 = 100)
1985	1042.933	36.8	1342.933	44.6
1990	1290.133	45.6	1034.667	34.4
1995	1395.467	49.3	1764	58.6
2000	1513.333	53.5	2204.8	73.2
2005	2830.4	100.0	3010.133	100
2014	6521.333	230.4	9197.333	305.5

Source: General Authority of Statistic, 1985–2014.

Table 3.7. Change in Quantity of Importing Food Products to Saudi Arabia since 2005.

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Food Products (Thousand Tons)	13738	15016	15989	18445	18096	19787	19581	22557	25547	25518
The Change (2005 = 100)	100	109	116	134	132	144	143	164	186	186

Source: General Authority of Statistic, 2005–2014.

Table 3.8. Self-Sufficiency Ratio of Several Products of Food in Saudi Arabia between 2002– 2013.

	Wheat	Cereals, Total	Vegetables	Fruits	Meat	Eggs	Fresh Milk
2002	100	33.7	80.2	60.7	52	102.2	107.4
2003	NA	NA	NA	NA	NA	NA	NA
2004	99.9	40.3	83.9	63.4	51.8	102.3	110
2005	NA	NA	NA	NA	NA	NA	NA
2006	100	37	84	61	50	117	103
2007	100	23	86	63	49	117	105
2008	43.5	18.4	91.2	62.4	46.7	104.5	102.6
2009	43.5	13.2	89.4	60.5	45.2	112.5	104.9
2010	45.5	11.5	86.9	57.9	41	108.7	103.4
2011	36.5	11.3	92.3	57.5	40	120.4	104.4
2012	27.6	7.4	88	57.4	41.2	117.7	112.4
2013	23.8	5.2	82.7	53.6	39.7	122.7	112.3

Source: Ministry of Agriculture, 2002–2013.

Furthermore, the self-sufficiency ratio could explore more about the change in reliance on imports for food products. Table 3.8 shows the self-sufficiency ratio change in Saudi Arabia for several groups of food, e.g., cereals, vegetables, fruits, meat, eggs, milk. In addition, I include wheat, which is included under cereal products, because of the potential impact of the government policy. Saudi Arabia has a surplus (more than 100%) from two products (eggs and milk), and the surplus from these commodities have increased through time. Vegetables have stability in the self-sufficiency ratio in time period of study, which was around 80%. For fruit products, the self-sufficiency ratio increased to 63% in 2007 then fell back to 54% in 2013. The self-sufficiency for cereals and meat decreases through time (2002–2013) from 34% to only 5% and from 52% to 40% for cereals and meat, respectively. Cereal commodities have a large impact on new food policies toward reducing reliance on domestic food production. Wheat, barley, sorghum, and millet represent 80% of consumption of cereal products in Saudi Arabia in 2013. Wheat crops are a major commodity targeted by the new policy to reduce domestic production, which the self-sufficiency ratio decrease from 100% in 2007 to only 24% in 2013 (Table 3.8), and the government target to depend on global market for all of its needs from this product in 2016; 78% of cereal products imports in 2013 was from wheat and barley crops. Increase in the imports of these commodities have helped make the Saudi market more sensitive to the change in price or quantity in the global market.

3.6.1.4 Fluctuation and rising food prices

Fluctuation and rising food prices are a main challenge for countries that target to improve food security levels for their residents. Higher food prices diminish the purchasing power for consumers and increase the share of their disposal income on food and especially for poor people with low income. Fluctuation and rising food prices in Saudi Arabia relate to the previous challenge of reliance on food imports for Saudi Arabia. The size of food imports continues to grow over time, which is mentioned in the previous factors of food security challenges, and food import values to Saudi Arabia were duplicated more than seven times between 1990 and 2013, according to the World Trade Organization data (2016). Therefore, the global market has a larger impact on domestic prices of food products, which means any factor affecting prices in the global market may have an impact on the final prices for consumers in Saudi Arabia. Reasons for the increase in the prices of food products globally could refer to several factors on the demand and supply sides (Woertz, 2013; Harrigan, 2014). On the demand side, the growth of world population, changing diets, and biofuel production are the factors putting pressure on price increases. On other side, the factors that have an impact on the increase of prices for supply reasons represent diminishing of agricultural productivity growth, impact of climate change on production, the expensive of input factors such as fuels and fertilizers, and restriction on food product imports from producers such as what happened in 2008 from Russia, Vietnam, India, and Argentina in order to secure domestic food needs.

Figure 3.3 is a snapshot for a situation of food price changes over time (2001–2012) in Saudi Arabia and compare them with the world average by taking the prices of 2002–2004 as the base (2002 – 2004 = 100). This graph includes the time of global food price crisis in 2007–2008 and 2011, which allows us to determine the effect of food price crisis in food security in the Saudi Arabia. The graph keeps track of food price index and price indexes for several products such cereals, meat, and dairy products. Food prices in Saudi Arabia were almost stable until 2007, except for meat, and they increase through the study time more than the food price index, while the meat price index in the world was less than the food price index since 2006. The opposite situation occurred for cereals and dairy products in the world, where the spike in the price index of these products could explain the spike in the food price index in 2008 and 2011. The highest value of the food price index during the period of 2001–2012 was around 230 (2011) in the world and 160 (2012) in Saudi Arabia. In conclusion, the fluctuation and increase in world prices for all food products more than change in Saudi Arabia (Figure 3.3). The interpretation of more stability for food prices in Saudi Arabia than in world impute to the Saudi government's policy; the government enhanced food security in the country through subsidies and storage of some food products. The Saudi government pays subsidies for staple food products such as wheat, rice, and dairy for producers and importers to guarantee stability in domestic prices and become less exposure to price variations in global market.

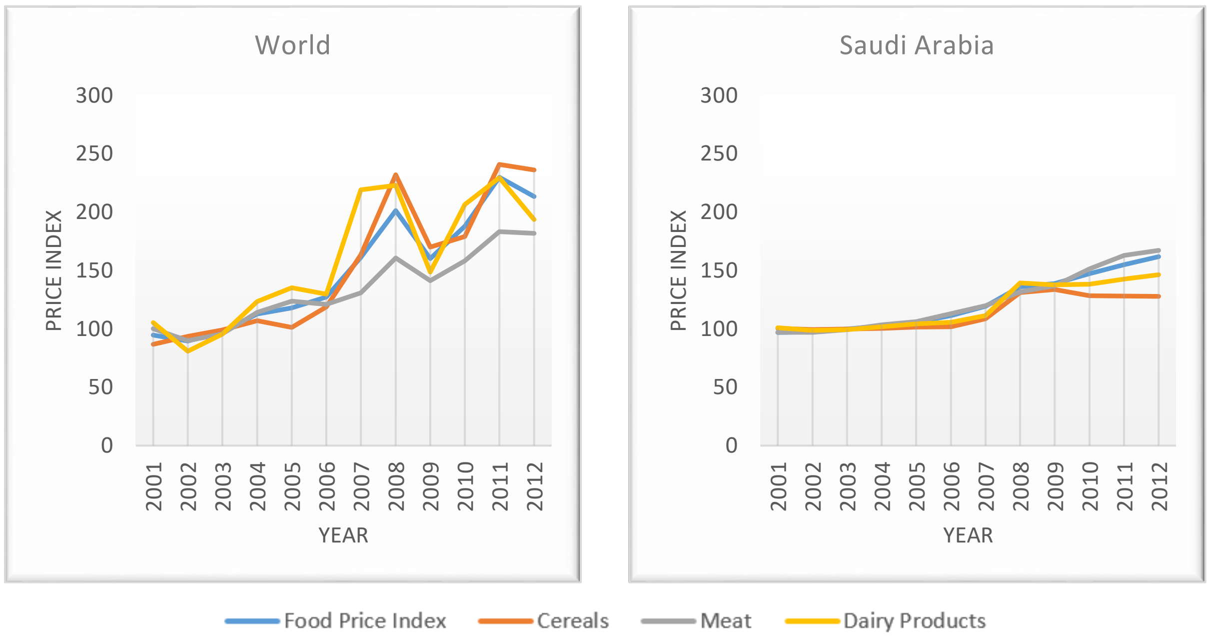

Figure 3.3. Change in Price Index for Several Food Products in the World and Saudi Arabia (2002–2004 = 100). *Sources:* FAO (2016); General Authority of Statistics (2012).

3.6.1.5 Food consumption habits

The behavior of food consumption has an impact on food security pillars such as availability of food needs, ability to food access, or food utilization. Thus, any change in food consumption habits could affect at least one of them. Therefore, this part explores the change in food consumption behavior and other things related with it such as food wasted and the change in situations of some diseases related to food consumption, such as obesity.

Checking the balance sheet data for consumption from the Food and Agricultural Organization could give evidence for change in food consumption in Saudi Arabia. The rate of calorie consumption per capita per day increased by around 80% from 1700 calories in 1961 to 3100 calories in 2011 (Table 3.9). The consumption of rice and wheat represents a third of total resources for energy intake since 1961, with a small increase in the rate compared with other energy intake resources by 5% in 2011. Further, more energy intake from wheat than rice and calories from wheat increased over time to represent only a third of resources of energy intake such as in 1977, 1985, and between 1989 to 1992. In addition, the proportion of energy intake resources from meat products increased from 3% to 7%. The energy intake from poultry represented 3% from total energy intake from meat products in 1960s, while lamb and goats represented 60% in the same period of time. Later, poultry consumption increased, for which the average dietary energy intake per person from poultry increased from only 3 calories in 1961 to 167 calories per capita per day in 2011. Therefore, poultry represent around 65% of meat energy intake in last decade (2000–2011), while 17% of energy intake from meat resources came from lamb and goat meat in 2011. This change in food consumption could be attributable to the income growth, government subsidies for some food products, and the change in structure of population due to the increase in the number of foreign workers.

One of four food security dimensions is utility dimension, which is association with food consumption habits and means any change in consumption could have a negative or positive impact on the utility. Some potential negative impacts for food consumption patterns is the prevalence of some diseases such as obesity and diabetes. The data of obesity and diabetes have not been available for long periods of time, but the recent data show Saudi Arabia as one of the highest countries in world for prevalence of these diseases. The obesity percentage between adult increased through the time from 32% (2010) to 35% (2014), according to the World Health Organization, which is higher than the world average (12.9%) and the average of high-income countries (23.5%) (WHO, 2014). Also, the statistic of diabetes prevalence from the World Bank shows a higher percentage in Saudi Arabia, of which 20% of Saudi's population, between 20 to

79 years, suffered compared with 8.5% for the world average in 2015 (World Bank Group, 2015).

Table 3.9. Change of Dietary Energy Consumption (Calorie/Capita/Day) in Saudi Arabia and the Contribution of Rice, Wheat, and Meat in Consumption during 1961–2011.

Year	Total Energy Intake (TEI) (Calorie/Capita/Day)	EI of Rice / TEI (Percent)	EI of Wheat / TEI (Percent)	EI of Meat / TEI (Percent)	EI of Lamb & Goat / EI of Meat (Percent)	EI of Poultry / EI of Meat (Percent)
1961	1717	14.79	18.05	3.20	60	5.45
1965	1857	13.73	19.60	2.80	55.77	7.69
1970	1888	13.19	20.23	2.97	48.21	14.29
1975	1795	15.09	28.41	4.96	29.21	26.97
1980	2885	12.31	26.76	6.52	23.40	44.15
1985	2703	12.13	30.52	7.03	24.74	45.26
1990	2871	6.58	31.91	6.51	22.99	54.54
1995	2852	9.92	22.89	6.69	25.65	55.49
2000	3113	13.52	22.87	7.13	23.42	63.51
2005	2973	11.64	27.18	7.16	21.13	64.79
2011	3122	12.75	24.27	7.88	17.07	67.89

Note: TEI = total energy intake; EI = energy intake.
Source: FAO (2016).

Also related to consumption habits is food wasted during consumption. Food loss and waste is a global issue; the FAO published a paper that mentioned food loss or waste represents one-third of total food production for human consumption (Gustavsson et al., 2013). Increased food wastage is not only related with decreasing food available for undernourished people but with other issues such as resource depletion (land, water, and fossil fuels) and increases in the emission of greenhouse gas; thus, reducing this wastage will contribute to improve food security (Munesue et al., 2015; Tielens and Candel, 2014; Shafiee-Jood and Cai, 2016). Food waste has become more of a threat in countries such as Saudi Arabia, which suffers from natural resources scarcity and reliance on food imports. The Intelligence Unit in the Economist compared 25 countries in loss and waste of food as one indicator for food sustainability, which included Saudi Arabia. The data show the food loss (pre-harvest) represent about 13% from the total of food production in the country compared with less than 1% in Australia and the United States. Also, Saudi Arabia was the worst country in food waste (during consumption), which was around 427 kg/person/year compare with an average of all countries in the study being 115 kg/person/year (Economist Intelligence Unit, 2016). The problem, also mentioned by some other research papers (Al-zahrani and Baig, 2014), was the expected large volume of food wasted during consumption. The reason for such a large amount of waste at the user level, according to Al-zahrani and Baig, is return to consumption culture in Saudi Arabia, of which there are huge quantities of food served in festivals. The policy response to address food wastage is weak and needs a more effective way to reduce it to enhance food security.

3.6.1.6 Population growth

One of the main reasons for the global food crisis is population growth, which has driven up the increase of food demand to meet nutritional needs. In addition, the increase in food demand as a result of population pressures leads to a rise in food price and puts pressure on economic resources in the country. Therefore, population growth will threaten food security in general and all dimensions of food security such as the availability and access of food. In the case of Saudi Arabia, the increase of food demand will require more domestic food production or increase food imports. The increase of domestic production of food will increase pressure on water scarcity, while the increase of food imports will lead to more reliance on imports.

Population data from Saudi Arabia show rapid population growth since 1974 to 2015. The total population increased from 7 million in 1974 to 31 million in 2015, which doubled more than three times over last four decades (Table 3.5). This growth is in reference to the increased

Saudi and non-Saudi population. The Saudi population increase by 200% since 1974; the fertility rate was around 3.5%–3% in last decade, but it decreased over time. The development operations in Saudi Arabia require more workers. Therefore, more emigrants (non-Saudi residents) moved to the country during the last three decades, which increased 12 times from only 700,000 to more than 10 million in 2015. In the future, more growth in population is expected but with a decreasing rate in Saudi Arabia. This population growth will increase the challenge of food security improvement in the country.

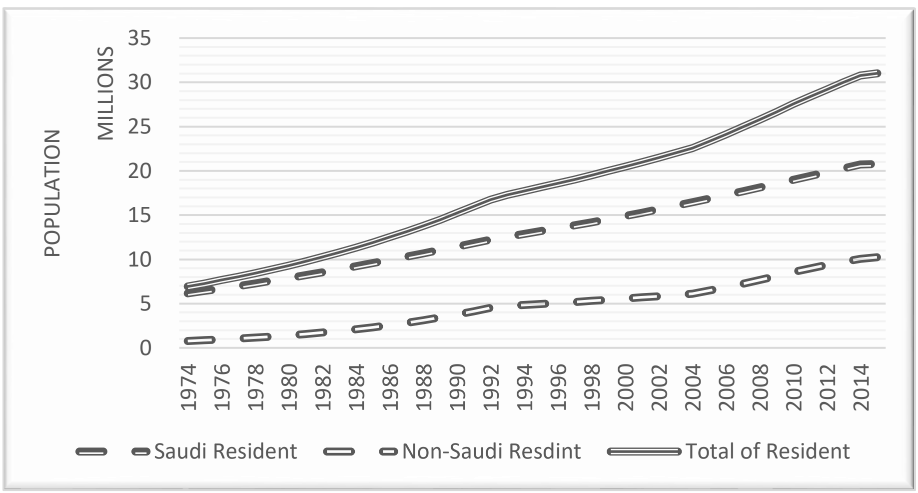

Figure 3.4. Population growth over time in Saudi Arabia (1974–2015).
Source: General Authority of Statistic (2012).

3.6.2 Advantage

3.6.2.1 High level of income

Income is a fundamental factor that has an impact on food security levels. The greatest contribution of income is to facilitate food access. In general, people with a high level of income would be able to obtain nutrient-rich foods and have the highest level of dietary diversity. Also, they are less sensitive to inflation in food prices. On the other side, poverty is the reason behind lack of food access and food insecurity. In addition, a country with a high level of income contributes to increase food access in several ways to guarantee that most residents have a good standing of food security. Governments around the world have implemented some development programs such build basic infrastructure (roads, storages, and port facilities), provide food aid, and subsidy staple commodities. In the EIU Global Food Security Index, high-income countries such as the United States and Singapore are in the top rankings for food security, while low-income countries such as Chad and Burundi have lower rankings.

Saudi Arabia is a high-income country, and the level of income is one advantage to keep people in the country with food security. The gross domestic product (GDP) was $646,000,000,000 in Saudi Arabia, according to the World Bank (2015), and its economy is among the 20 countries with the highest GDP in the world. The economy of Saudi Arabia maintains growth over time, whereas the GDP has increased more than three times since 2000 (Table 3.10). The government of Saudi Arabia is always working to secure food access in country and individual levels from high oil sector revenues by adopting several initiatives: for example, the subsidy of domestic agricultural production, and commodities imports of food staples. The share of food expenditures from total consumer expenditure in Saudi Arabia decreased from 26.1% (2011) to 25% (2015) but was still higher than global average, which was 22.7% (2015) according the data from the Department of Agriculture in the United States (USDA) (Table 3.11). Fortunately, the ratio of food expenditure is between 6.6% (2011) to 9.5% (2015) from GDP per capita in Saudi Arabia, which reflects the expenditure on food budgets per person. Therefore, high income is the reason behind food security in Saudi Arabia.

Table 3.10. GDP Change in Saudi Arabia since 1970.

Year	GDP Million Dollars (current US$)
1970	5377.33
1975	46773.37
1980	164541.74
1985	103897.85
1990	116778.10
1995	142457.68
2000	188441.87
2005	328459.61
2010	526811.47
2015	646001.87

Source: World Bank Data (2016).

Table 3.11. GDP Per Capita and the Ratio of Expenditure in Saudi Arabia between 2011–2015.

Year	GDP per capita (current US$)	Expenditure on Food per person (current US$)	Ratio of Food Expenditure to GDP per capita (Percent)	Ratio of food expenditure to Total Expenditure (Percent)
2011	23256.1	1,544	6.64	26.1
2012	24883.19	1,714	6.89	25.8
2013	24646.02	1,768	7.18	25.5
2014	24406.47	1,857	7.61	25.3
2015	20481.75	1,954	9.54	25.0

Source: USDA, 2016.

3.6.3 Current Policy for Enhancement of Food Security in Saudi Arabia

The previous section made it clear that several factors represent challenges to achieve sustainable food security in Saudi Arabia. At the same time, the country has a high return from the oil industry, which contributes to income stability for all residents, meaning easy access to food. Accordingly, the Saudi government takes advantage of the high income to face the challenges of food security by designing and implementing several policy programs to guarantee and secure food supplies at the country level. Therefore, the government established wheat storage and the Agriculture Fund to loan funds for agricultural projects or any industrial projects that support and contribute to food security. In addition, providing subsidies for staple food products smooths food access. Also, the government provided the initiative for abroad agricultural investments to support food security. Of course, the government always reviews these programs and its impact on food security.

3.6.3.1 Establish wheat storage

Wheat crops are primarily used for consumption in Saudi Arabia, as in the world. The size and prices of wheat such as demand size and environmental conditions (drought or floods) can have an impact on wheat consumption. Therefore, some countries target to maintain strategic reserves of wheat to reduce import supplies and price risks, and they expand those reserves over time to reduce the risk. For example, the USDA shows the change in stock for different countries. Globally, wheat stock increased in total by 35% between 2012 and 2015 from 177.5 million metric tons to 240.6 million metric tons. China, the United States, India, and European Union represent 63% of total wheat stock in the world (Table 3.12).

Table 3.12. Change in Stock Size of Wheat in the World from 2012–2015 in Million Metric Tons.

Country	2012/13	2013/14	2014/15	2015/16
Australia	4.66	4.56	4.84	6.14
Canada	5.11	10.40	7.05	5.17
China	53.96	65.27	76.10	97.04
European Union	10.71	9.94	12.74	14.01
India	24.20	17.83	17.22	14.54
Iran	5.12	7.30	7.92	8.18
Russia	4.93	5.18	6.28	5.60
United States	19.54	16.06	20.48	26.55
World	177.59	194.68	217.20	240.65

Source: USDA, 2016

In Saudi Arabia, when domestic production and the market were not able to meet growth in the wheat demand, the Saudi government established the Grains Organization in 1972 to buy grain products from domestic producers, store them, and mill them. Therefore, the goals of this organization are to guarantee the supply of grain products, whereas the maintenance of wheat products is among the most important. For this goal, the Grains Organization interest is to provide and store wheat products close to consumption and production places and to keep extra storage for emergencies. The Saudi government keeps this strategic storage for wheat to ensure there is enough for six months of consumption in 12 different places, and they are different in capacity, depending on population density. The capacity of this storage was 2.5 million metric tons until 2013, and it increased to 2.77 million metric tons in 2014. The organization targets to increase capacity of wheat storage to be enough for a year of consumption (Saudi Grains Organization, 2015). In addition, Saudi Arabia has stock from other grain products such as coarse grains and barley; this stock contained 4.37 million metric tons from coarse grains and 4.06 million metric tons from barley in 2015 (USDA, 2016).

In fact, the organization works to implement the government vision toward food security. Therefore, it bought domestic production of grains at subsidized prices when the government policy looked for self-sufficiency from wheat crops. Since 2008, the organization moved to the global market to import wheat and meet the demand after concerns for using large quantities of nonrenewable water in agricultural production, as shown in Figure 3.5.

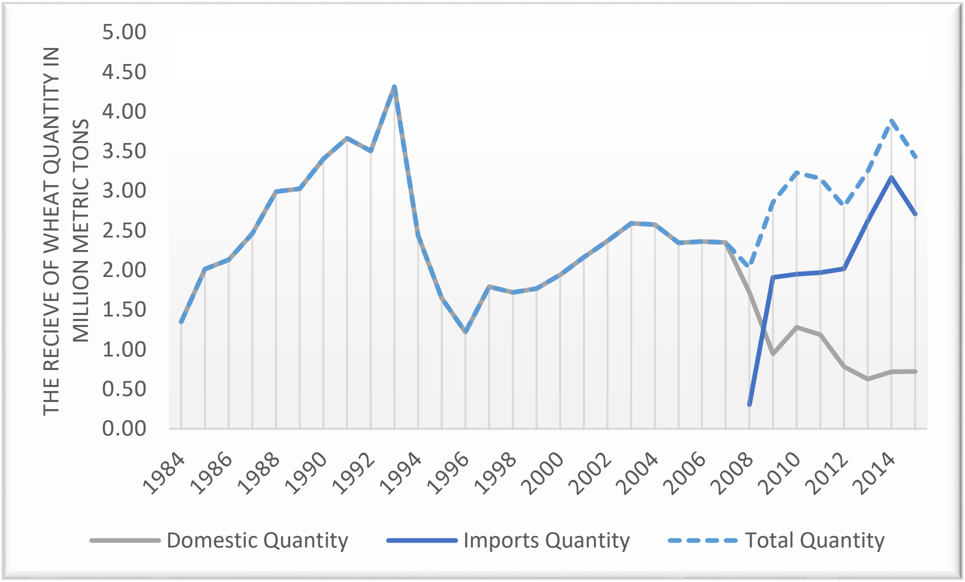

Figure 3.5. Change in source of wheat crop for Saudi Grains Organization.
Source: Saudi Grains Organization, 2015.

3.6.3.2 Establish Agriculture Fund

The government set a goal to establish the Agricultural Fund in 1963 in order to provide funds for projects in the agricultural sector to enhance investments in this sector and raise agricultural production and productivity by encouraging transfer and use a new technology. Therefore, the loans are paid for any project that may contribute in a horizontal or a vertical expansion in the agricultural sector to obtain the final goal of providing a high level of independence and stability of food needs. Thus, the loans increased through the years to include engines, pumps, digging wells, cars, tractors and agricultural machines, fertilizers and seeds, livestock, buildings, fuels, and other inputs for agricultural projects to the efficiency and guarantee to raise the contribution of this sector in GDP, as shown in Table 3.13.

Table 3.13. Annual Value and Number of Loans by Saudi Agricultural Development Fund since 1980.

Year	Number of Loans	Amount of Loans (Million Dollars)	Year	Number of Loans	Amount of Loans (Million Dollars)
1980	45128	671.32	1997	3942	166.30
1981	37446	777.96	1998	5607	238.01
1982	38886	1184.62	1999	6628	239.53
1983	23844	927.26	2000	6147	295.02
1984	14746	615.86	2001	8037	383.27
1985	9209	411.47	2002	7017	392.69
1986	7063	270.34	2003	2254	162.38
1987	4792	223.15	2004	5136	276.90
1988	3750	200.14	2005	3527	237.67
1989	4142	226.61	2006	4303	256.81
1990	4123	269.67	2007	3770	277.00
1991	3733	200.75	2008	2701	210.04
1992	4374	205.61	2009	2360	227.09
1993	4429	246.83	2010	2857	199.76
1994	3822	177.87	2011	3291	243.08
1995	2642	109.44	2012	3590	245.20
1996	3065	114.51	2013	4524	278.08

Source: General Authority of Statistics in Saudi Arabia

The Agricultural Fund contributed to the implementation of agricultural policies. Thus, a higher annual amount and number of loans were spent between 1980 and 1985, when the government desired more investment in agriculture. Then, these amounts and number of loans decreased to target specialized projects to achieve objectives of agricultural policy. After 2008, the fund adjusted loan conditions with new agricultural policies; thus, the loans provided for projects that contributed to food security and decreased reliance on food imports resulting from population growth, including nonrenewable water resources such as hydroponics projects, greenhouse farms, and poultry projects. The fund also included the provision of credit facilities and concessional loans for agriculture abroad investment projects from Saudi investors as one of the new initiatives to enhance Saudi food security.

3.6.3.3 Food subsidies

Supply and demand has raised the prices of food commodities for several reasons, as previously illustrated. This rise has affected consumer budgets and created difficulties to get food for those with low and middle levels of income. Saudi Arabia followed a policy that supported food prices as one way to create easy access to food for all residents and maintain stability of food security, which does not affect the fluctuation of food prices in the world market. The government provided several forms of price support such as import subsidies, direct production subsidies, and consumer subsidies. In general, the government focused on the subsidies for seven food products: rice, barley, wheat, sugar, meat, soybean, and feed (Almutiri, 2013).

The Saudi government provided import subsidies represented in direct (cash) payment for several commodities such as for rice in 2007 at around $267 per ton, then reduced it with a price decrease in 2009. It also paid import subsidies for some feed processing inputs and subsidy payments, depending on world market price. USDA reports note the amount of subsidies for feed processing inputs as follows: soybean meal ($137 per tons), corn ($82 per tons), distillers dried grain with soluble ($99 per tons), corn-gluten feed ($91 per tons), and corn ($82 per tons) (Al-Saffy and Mousa, 2010; Ahmed and Mousa, 2016). Reducing import tariffs is another policy; for example, the Saudi government reduced the 25% tariffs on imported wheat products (by value) to 0%. Also, the tariff is reduced by the government from 25% of its value to only 5% for some other food products such as poultry products, eggs, cheese products, vegetables oil, pasta, food cans, juice, drinking water, and milk (Saudi Press Agency, 2013).

The direct production subsidies paid for some agricultural products such as barley and wheat since the 1980s. For concerns regarding large water consumption, the government terminated this program in 2003 for barley and reduced it for wheat. In 2007, the government planned to stop wheat production and only will pay $267 per metric tons until 2016. For consumer subsidies, the products of the Saudi Grain Organization sell at a fixed price for almost 30 years whereas wheat flour sells at $0.32 per kilogram, while average retail price was $1.33 per kilogram in 2014. Also, the Grain Organization fixed the price to sell 50 kilograms of barley at $9.6 (Ahmed and Mousa, 2016).

3.6.3.4 Agricultural investment abroad initiative

The adoption of investment overseas in agricultural production was a new initiative of the Saudi government in 2008 to create stability of food supplies over time. Several reasons encouraged the launch of this program by the government, which are represented in the increase of food gaps between supply and demand, water scarcity in the country, sharp increases in global food prices, and restrictions of food exports from some countries. As shown in Tables 3.5 and 3.6, the food gap increase in the last decade in the country led to more increases for the value and quantity of food imports. In addition, water scarcity and use of around 90% of water consumption for agricultural usage are the main reasons to stop most of the domestic programs to achieve self-sufficiency from some crops, which consume more water by supporting domestic food producers from the government, which leads to decreasing self-sufficiency from some grains products and look for alternative ways to produce the food. In addition, some food exporter countries such as India, Russia, Pakistan, Argentina, Kazakhstan, Vietnam, and Ukraine, as a result of the food crisis in 2007/2008 imposed resections on exports of some crops such as rice, wheat, and maize (Food and Agriculture Organization, 2008).

The new policy of targeted agricultural investment abroad is intended to enhance food security in Saudi Arabia and complement the other ways to achieve food security, which is not a substitution for any of them. The new policy aims to support and encourage the private sector in Saudi Arabia by having the government invest in the agricultural sector even in crops or animal production overseas. This initiative is based upon integrated partnerships with other countries that have good circumstances for agricultural production such as land and natural resources. The Saudi government's tasks in this initiative are to finance and protect the investment through agreement with host counties. In addition, the government of Saudi Arabia could contribute in the finance for infrastructure projects in investment regions in host countries through government financing funds and international development funds. The condition for any investor or country who needs to join this initiative is to guarantee exporting part of the project products to the Saudi Arabia market for at least 50% of the output. Therefore, food security targets from decision-makers in Saudi Arabia are based on three parallel directions: domestic production with taking care of water scarcity, imports of food commodities, and agricultural investment abroad.

The investment abroad in agricultural projects is not a unique innovation or special idea for food security by Saudi authority with their investors; Von Braun (2009) listed 55 agreements between different governments or private sectors with host countries during only three years (2007–2009). These agreements include investors from China, Qatar, India, Djibouti, Libya, Egypt, Jordan, Kuwait, Saudi Arabia, South Korea, United Arab Emirates, Vietnam, Bahrain, United Kingdom, South Africa, United States, Germany, Sweden, Japan, and Denmark, whereas the host countries include Congo, Ethiopia, Kenya, Malawi, Mali, Mozambique, Sudan, Tanzania, Zambia, Cambodia, Indonesia, Laos, Pakistan, Philippines, Turkey, Ukraine, Angola, Madagascar, Nigeria, Russia, Egypt, Chania, and Brazil. In the specific case of Saudi Arabia, the staple food commodities are targeted through investment abroad, which includes wheat, rice, barley, corn, sorghum, soybeans, sugar, oil seeds, green fodder, livestock, and fisheries. Candidates for host counties include Sudan, Egypt, Ethiopia, Turkey, Ukraine, Kazakhstan, Philippines, Vietnam, and Brazil. In fact, the strategic reserve of food crops is a complement factor with this initiative to avoid any food crisis (Al-Obaid, 2010).

Implementing the Saudi agricultural investment abroad contains positive aspects and benefits, while it will face some challenges that need to be dealt with. The one benefit of this project is represented in the enhancement of food security and the increase of the global food supply, which will contribute to provide a balance in the food global market and prevent sharp rises in prices. For the host countries, foreign investment in agricultural sectors could create jobs in rural areas, provide part of food needs domestically, and increase the government's revenue from taxes and exports fees (Shepherd, 2013). Furthermore, it will take advantage of capital, technology, knowledge, and experience from the Saudi private sector, along with contributions in development for investment areas. In addition, providing Saudi's needs from some staple commodities in case of global crisis. Also, taking a benefit of abundant natural resources such as water and arable land and the availability of laborers. On the other side, political challenges and instability could threaten the investment in some countries, even though targeted countries have established political systems for choosing investments. There are also unclear regulations and procedures, and the absence of guarantees for an agreement commitment. In addition, investors also may suffer from poor infrastructure conditions in host counties, which they could bear the cost to compensate from that. It is important for the Saudi government to understand the prospective challenge in that some host countries that suffer from shortages in food commodities and depend on imports for food needs; food exports could cause some concern for the residents, even the initiative of agricultural investment abroad targets to meet some domestic and global needs of food (Woertz, 2011).

Unfortunately, several agricultural investment projects overseas, initiated by investors from Arab Gulf countries, failed to take off in countries such Indonesia, Egypt, and Sudan for different reasons, as mentioned above. Specifically, the reason could refer to financial crisis and its effect on financial situations for investors. Also, the revolutions in some Arab countries in 2011 is another reason for withdrawal from some project from foreign companies; there is suspicion in the agreements with previous political systems (Woertz, 2011). For these reasons, it is important to evaluate this program after almost 10 years of its release.

3.6.4 Future Directions for Food Security in Saudi Arabia

The food security policies as shown above in this chapter have gone in different directions in Saudi Arabia since 1970 from self-efficiency policies to be more import reliant in order to preserve nonrenewable water resources. Food security is still an issue in the desert country during different strategies and face group factors of challenge. Therefore, the next question is about the expected change in food security policies in the country. Recently, the Saudi government released the development vision in the country through 2030, which allow us to know the future direction of policies that are related to food security. Therefore, I am focusing here on any part of the Saudi Vision 2030 that addresses any aspects of food security. Food subsidies, food industries, strategic food reserves, aquaculture, agricultural investment abroad, renewable water sources, and reduction of any resource wastage are topics related to food security mentioned in Saudi Vision 2030.

First, the government has supported the prices of staple food commodities for around three decades through direct subsidies for producers, and consumers, or exemption of some of customs fees such as in rice, wheat, poultry, or feed products. Right now, the subsidies are provided to everyone in the country regardless of his income level and status of residency; the government guarantees easy access to food commodities via lower prices in the domestic market compared with the global market. The 2030 Vision target to be more efficient and fair in subsidy payments only for those included in government care with a lower level of income. The new policy will allow the government to avoid to paying subsidies for who do not suffer from increase in food prices and solving one of the essential issues in food security by reducing food waste, which is one reason food waste refers to the low price of food commodities.

In addition, food industries are the other factor that play an important role to increase food security levels as noted in Saudi Vision 2030 to support other companies that make additional values for the economy. Specifically, food industries reduce waste of some agricultural products, which is characterized as fast damage or having a seasonal period of production such as with tomatoes and dates. Also, food industries could contribute to decrease the reliance on food imports. Recently, the food processing sector grew in Saudi Arabia; the number of firms in this sector increased from 460 in 2002 to 732 in 2012 (Ahmed and Mousa, 2014). The amount of imported processed products remains large and needs more domestic investment in this sector. Ahmed and Mousa point out that the majority of imported food products are high-valued final products, whereas some of them are raw material available in the domestic production such as frozen meat, processed vegetables, fresh vegetables, fish and seafood products, and condiments and sauces.

In the section of protecting vital resources, the vision of Saudi Arabia points to othergoals related to food security; these policies toward food security already are implemented through current policies such as having strategic food reserves, creating partnerships with other countries to overseas investment in agricultural production, and rational use of renewable water resources. Besides, the government will encourage the aquaculture practice to take the advantage of the long length of beaches for the country on the Red Sea and Arabian Gulf (2640 kilometers). The current production size of aquaculture is 30,000 metric tons, according to the National Transformation Program, which is the first step to achieve the 2030 Vision, while the target is 100,000 metric tons in 2020. As previously mentioned, the one important challenge that faces food security in Saudi Arabia is the high rate of food waste per person compared with the global range; this waste in food has led to waste in the natural resources used to produce these foods. Fortunately, the government of Saudi Arabia targets to work on reducing the wastage of food and natural resources in processing, distribution, and final consumption through the 2030 Vision.

3.7 Conclusion and Recommendations

Saudi Arabia could reach a good level of food security compared with other countries, according to several food security measurements. This refers to several policies of the Saudi government to invest large revenues from the oil industry to achieve development in the country, whereas food security represents one aspect of development. In the early stages of development planning, the government targeted to guarantee food supplies and achieve a self-sufficiency from some agricultural products by supporting domestic agricultural production. This has led to development in domestic production and extensive use of technology in domestic agricultural production, which contribute to more production efficiency. Also, the government supports final food prices to ease food access for all residents in different income levels. Unfortunately, some of the government policies, such as subsidies for the domestic wheat production, which consumed a lot of water, were inefficient and contributed to more threats of food security. Recently, the government adopted some policies to keep sustainability in food security such as support for the domestic production of crops that consume less water, support overseas investment in agricultural production, increase the capacity of wheat strategy storage, and target to reduce the wastage of any resources. Even so, food security in Saudi Arabia still faces several challenges that threaten sustainability such as political instability in the Middle East, water scarcity, reliance on food imports, and fluctuations and increase in food prices, food consumption habits, and population growth.

In subject of circumstances of Saudi Arabia, the new policy toward food security in last 10 years is better to fit the situation of the country. Especially, the new prospective of food security in the government vision for 2030 will keep the country in a good standing level of food security. For purpose of obtaining sustainable food security, here are some recommendations:

1. According to the large change in Saudi Arabia's policies toward food security from more depend on domestic production from grain products and spend money to encourage agricultural sector to be more relying on imports of food, which it was major shift in food security policy in last decade. That leads me to recommend to seek more stability in government's policies toward food security and build them on accurate data to avoid changing them in a short time, which is important for sustainable food security and increase the investment in food sectors.
2. Obtaining more diversity in food consumption in general does not have any evidence that relate to improve the situation of food security according the result of this association in chapter 2. While, obtaining diversity in countries that represent food sources is important to avoid a big change in food supplies for any circumstances in the origin country. This consistent with the review of impact the food prices crisis on Saudi Arabia, when the export

ban occurred for some food products from some export countries for different reasons in 2007–08 (Food and Agriculture Organization, 2008).

3. Because of water scarcity situation in Saudi Arabia and large usage of water in agricultural practices, taxing some agricultural crops that consume more from nonrenewable water resources or setting fees for using water in agricultural practice to obtain efficiency in usage of water by including water usage in production cost is another recommendation.
4. Given the information from the Economic Intelligence Unit, Saudi Arabia had the highest percentage in food waste during the consumption. So, more control on food commodities subsidies by paying the subsidy for who need it such as low level of income could contribute to reduce food wastage.
5. Overseas investment in agricultural production for Saudi’s private sector is a risky project for any change in economic and political circumstances in host countries, which may require investment in infrastructure of the host country besides other cost production projects, while it could cause sensitivity for a country that suffers from food insecurity (Woertz, 2011; Shepherd, 2013). Therefore, it is important to reduce the risk in these projects by supporting the agricultural development through providing loans and modern technology for domestic producers in host countries, then buy output by market price for a country that suffers from political instability instead of operating a large project. This option will lead to increase in agricultural output and will be enough for the domestic market and export surplus. The other option for a stable country could be through building partnerships with local companies.
6. Improvement of the food industry sector has a benefit for food security and the domestic economy. At the same time, it does not face the same challenge that faces food production in agricultural operations and especially those related to consumption of water, which there are

opportunities in this sector to grow and decreasing the food gap of some commodities (Ahmed and Mousa, 2014).

7. A big advantage of food security in Saudi Arabia comes from oil industry revenue. As mentioned before, governments of Saudi Arabia have used this revenue to finance several programs to get a stable level of food security and overcome several challenges that face country; thus, any change in this revenue will threaten food security. Therefore, it is important to build the Saudi economy upon different sectors.

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