Mendel University in Brno
Faculty of Business and Economics

The theory of population and estimation of the stationary state

Diploma thesis

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Abstract

Gavrilovets, Natalia. The theory of population and estimation of the stationary state. Diploma thesis. Brno: Mendel University, 2017.
This diploma thesis focuses on the estimating of the time of possible future stationary state of population. Different theories of population are discussed and reviewed. The calorie model of food supply and demand is taken as the basis of the thesis. The research offers the estimated calorie model, the calculations of time of possible future stationary state and possible scenarios of future changes in the model.

Keywords

Population problem, Population theory, Stationary state of population, Food supply, Food demand, Food production, Food consumption, Population growth, Malthusian Theory, Ester Boserup Population Theory.

Abstrakt

Gavrilovets, Natalia. Teorie populace a odhad stacionárního stavu. Diplomová práce. Brno: Mendelova Univerzita, 2017.
Tato diplomová práce se zabývá odhadem doby možného budoucího stacionárního stavu populace. V práci jsou probírány a přezkoumány různé teorie populace. Základ práce představuje kalorický model nabídky a poptávky po potravinách. Výzkum nabízí stavbu kalorického modelu, výpočty doby možného budoucího stacionárního stavu a možné scénáře budoucích změn v modelu.

Klíčová slova

Populační problém, Populační teorie, Stacionární stav populace, Nabídka potravin, Poptávka po potravinách, Produkce potravin, Spotřeba potravin, Populační růst, Malthusianova teorie, Ester Boserupova populační teorie.

Content

1 Introduction

The Theory of population has been popular in the scientific world since the ancient times. After the book by Thomas Malthus was published in 1798 the population problem has become the part of the content of almost every economic theory. Since that time a lot of different economists tried to explain the understanding of the Theory of population and the possibility of achieving of the stationary state. Two main population theories represent the opposite opinions - Ester Boserup and Malthus ones. This two theories help to understand the basics of the views about population growth better.

The reason why this topic stays still so popular in the modern world is the existing problems with food supply systems and still high rate of people suffering from the undernourishment. While the high population growth, especially in the developing countries, pushes the food demand, the food supply has to grow faster and faster to satisfy higher and changing needs of population. So there is always a question to arise if it is possible to provide the growing population with enough amounts of food resources. And even while population growth tendencies changed a lot during last 100 years, the population growth rate stays still high for the poorest countries.

The diploma thesis will represent the main population theories and their main ideas. This research shows the development of the thoughts about population growth and the nowadays state of population. Another part of the research concerns another side of the problem - the food supply. These two sides of the population problem have to be compared and analyzed to estimate the possibility of stationary state to come.

2 The problem and the aim of the thesis

In the first chapter the main problem and the aim of this diploma thesis will be presented. Also the ways of solving of the objective of the paper will be described here.

2.1 The problem of the thesis

The growing demand for food is provided by growing number of population and changing food preferences. This is a big challenge for food supplying chains and agricultural production. The main question of the population problem stays the same for many years – is it possible to satisfy this growing demand.

This is the question of stationary state to come. So if stationary state is possible in the future, it means that there will be the year in the future when food demand equalizes food supply. In fact, it also means that further population growth would not be supported with enough food production growth. On the other hand, if stationary state is not possible in the future, it means that Malthus was wrong with predicting the population growth to be higher than growth of the agricultural production.

So this problem will be solved in this thesis by an attempt of calculation of the time of possible stationary state.

2.2 The aim of the thesis

The suggested aim of the diploma thesis is to estimate the calorie model and the timeframe of the stationary state. There is also a need to determine the real food demand and real food supply in calories firstly.

The following steps could be taken to reach the main aim of the research:

1. Review of the literature and summarizing already existing theories and knowledge about the population growth, consequences of the high population growth, food production, food consumption and different theories of population.
2. Developing the methodology of the research. This will include the formulas and equations which will be used for calculations and collecting the data sets about the number of population, food production, food demand and food supply.
3. Recalculating the collected data sets and main calculations of the time of the achieving of the stationary state through analyzing the data in calories.
4. Building the possible scenarios changing the state of food supply and demand
5. Discussion about the applicability of the suggested model and calculations and conclusions about the results of the research.

3 Literature review

Literature review is the chapter that is providing detailed overview of the literature sources describing the population problem. Different published and internet resources about population, food problem and stationary state, such as papers, books, researches, official publications and reports of the international organizations, were used for the literature review. The main theories of population growth and the main ideas of their authors are described in this chapter as well as the main definitions are given.

3.1 Population growth and main definitions

In this section all main definitions of population growth and its factors are mentioned and subscribed. Also the main consequences of uncontrolled high population growth are described. So this section gives understanding of what the population growth is, what actually influences the population growth and what the possible results of population growth are.

3.1.1 Population growth

The world population number is projected to grow to around total 9 billion by 2050 (UN, 2010). Such high growth of the population implement crucial challenges in meeting future food demand.

Population growth is not only a demographic factor. This indicator influences economic situation, food security, standards of living, ecology and many others macro and micro indicators. During the last centuries high population growth started to be associated with poverty, famines and diseases. In the developing countries the high birth rates led to very negative consequences. All this means that overpopulation can be dangerous and makes high population growth one of the main global problems of the twentieth and twenty-first century (Thirlwall, 2006).

It is very important to understand what does the population growth mean. Population growth is usually measured as population growth rate. The definition of this term is given by many international organizations. The United Nations describes population growth rate as following: "*A population's growth rate is the increase (or decrease) in the number of persons in the population during a certain period of time, expressed as a percentage of the population at the beginning of the time period*" (United Nations, 2016).

The definition of the world's population growth is little bit different from the definition of population growth of one country. As the population growth of some territory is determined by the three factors: fertility, mortality, and international migration. Population size of the whole planet and its growth depends only on two of them: birth rate and mortality or death rate. It is also called "natural growth of the population" (World Health Organization, 2017).

Governments of number of countries have already accepted the percentage goals for the population growth level. In 2005, 19 per cent of countries proclaimed their population growths to be too slow, 42 per cent of the countries stated that they think that with their rates of population growth are acceptable and 39 per cent agreed that the rates are too high for their countries (United Nations, 2016). More than a half of developing countries had their rates of population growth on the higher level than they wished to have, and 80 per cent of the least developed countries stated the same fact (United Nations, 2016).

The growing population number is the great global challenge. And first of all it is a great challenge for the agricultural production sector. The higher is this population pressure the more important the population problem becomes.

3.1.2 Fertility and mortality

Fertility and mortality are two main determinants of the population size and growth. The evolution of these two variables leaded to crucial changes in dynamic of the population growth.

The fertility is usually measured as a total fertility rate. This total fertility rate is representing "*the average number of children a woman would bear over the course of her lifetime if current age-specific fertility rates remained constant throughout her childbearing years (normally between the ages of 15 and 49). The current total fertility rate is usually taken as an indication of the number of children women are having at the present*" (United Nations, 2016). "*While total fertility is an average number of children a hypothetical cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates of a given period and if they were not subject to mortality. It is expressed as children per woman*" (United Nations, 2016).

While most of the World's regions are supposed to get to the replacement level of fertility which means that living population just replaces itself from one generation to another sub-Saharan Africa's population is the one to be almost doubled during next 20. The figure below shows current and projected total fertility rates for different regions (World Resources Institute, 2013). So it is visible that even while the tendencies in changing in the fertile rates are expected to be different in different regions, the global tendency of decreasing fertility rates is expected for all the countries. This may lead to low population growth rates in the developing countries.

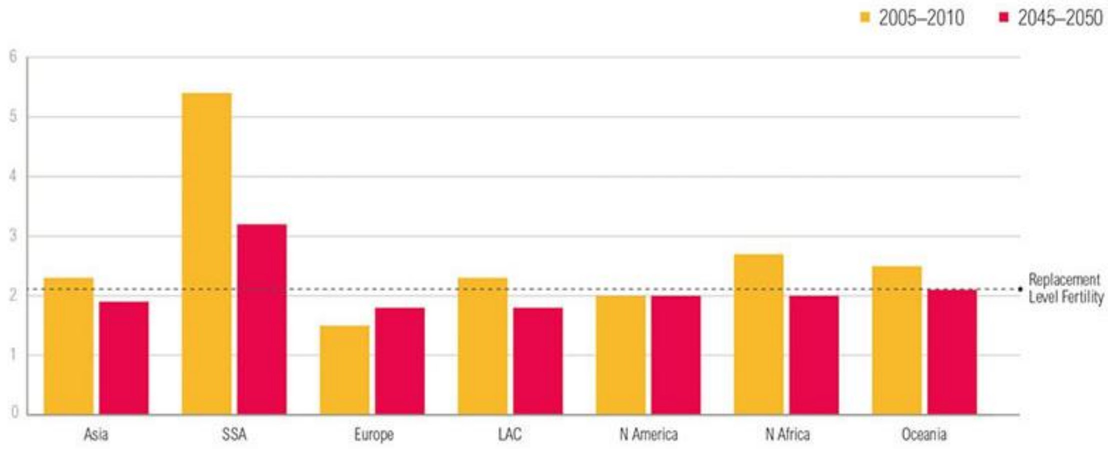

Fig. 1 Current and Projected Total Fertility Rates
Source: World Resources Institute, 2013

Mortality is usually indicated by mortality rate or death rate. Sometimes the term "crude death rate" is used.

So mortality rate is calculated as *"a number of deaths occurring in a given population at risk during a specified time period (also known as the recall period). In emergencies, usually expressed as deaths per 10000 persons per day; alternatively, as deaths per 1000 persons per month or per year"* (World Health Organization, 2017).

It is very important to understand what influences these two factors – fertility and mortality. The four main factors can be identified. They are GNP, infant mortality, agricultural production and female illiteracy. The relationship of these four factors and mortality and fertility rates will be described in following paragraphs.

The higher is the income of the average family the higher are their standards of living. This means that these families will probably use the family planning and will prefer having less children to provide them with good education. Also willingness to have children is higher, especially in poor countries, when the numbers of agricultural output over GNP are larger (Labini, 2001).

Low education level is strictly associated with higher numbers of children born. It is explained by many factors. For example, uneducated women use less contraception. Also if women have some education, most probably they wish to have a job, so they would not have so many children (Labini, 2001).

Education of women and their involvement in the global economy play very important role in the fertility rates dynamics. During last century in the developed countries these factors changed the statistic of the fertility rates dramatically. In the developing countries female literacy influences also rates of child mortality, because in these countries, where the level of medical help is very low, mothers sometimes are the only ones who take care of child's health (Sen, 1999).

Also we can mention that high birth rates stimulate mortality rates itself. Especially when it comes to early births which can cause maternal death and prematurity deaths (National Academy of Sciences, 1971).

3.1.3 Bad consequences of overpopulation

Fast population growth leads to overpopulation which can create many other problems in different spheres. The empirical evidences of this are the nowadays situations in the most of the developing countries.

Some scientists and economists blame high population growth for almost all the global problems of the modern world. They claim that high population growth has at least three negative effects on the humanity nowadays. First, it stimulates poverty - the number of population that is living in poverty and the level of the poverty. Second, it has crucial impact on environmental - the aggressive usage of natural resources. This results in bad living conditions. Finally, it prevents the productive and innovative economic growth by holding back the savings and investment (Anderson, 2013).

Of course one of the biggest problems of the growing number of population is the growing need of resources, especially food or agricultural production. It pushes the need for more productive agricultural techniques which can provide people, on the one side, with larger amount of food and, on the other side, decrease the food prices to make this food available to all the people. From one point of view governments are interested in keeping food prices low to be popular with their voters. But it means that food producers stop getting large profits which make food production not so attractive for the new entrepreneurs. Low profits also do not stimulate the innovations (Revelle, 1984).

The population growth is a great stimulator of the global urbanization process. People from the rural areas are migrating to the cities where they hope to find better living conditions, more jobs and infrastructure benefits. In fact, in the developing countries it turns out into demographic catastrophe. The population of some cities is growing so fast that infrastructure is not capable to manage it. So the living conditions there are even worse than in the rural areas. Some districts of such cities becomes real bedding of criminals, diseases and poverty (Villarreal and Stloukal, 2005).

Not only people migrate from rural areas to the cities, overpopulation stimulates global migration a lot. People from poor overpopulated developing countries try to find their new home in rich developed countries. This process has its pros and cons. The immigrants get the chance for a new start in a country with better living conditions, but they have to change their culture preferences most of the times. Countries-recipients get low paid workforce but have to fight with many other negative social, political and economic consequences of migration (Martin, 2001).

Large population and high population growth results in high population density. And the areas with high population density usually are the areas where diseases are spreading faster. Most of the diseases are easily expanding through water and food resources. In the most crowded areas the level of hygiene is not enough to provide clean water and good quality food which results in burst outs of many diseases. Some epidemics can be also caused by already infected insects (Macfarlane, 1997). One more reason of epidemics is not enough usage of contraception in these counties. This case cause both high population growth and spreading of such diseases as HIV/AIDS (Gordon, 2007). High birth rates in the developing countries results in health problems of both women and children. Especially when we talk about teenage pregnancies and early births. But the main problem is still low level of medical services. Medical help is still unavailable for many people in the developing countries. In such areas medical care systems are not capable to take care of all the population and people cannot afford private medical clinics and doctors. Health problems leads to economic problems too as far as health care system is state expense mostly and bad health usually results in bad productivity.

Medicine is not the only sector of state expense of public economy that is under great pressure because of the fast population growth. Another important point of expenses is education system. Education system does not only provide the better future for the concrete people, it also results in better future of the whole country. So the lack of education also influences the economic situation of the country. Unfortunately, in countries with high population growth rates the average level of achieved education stays pretty low. Big families usually cannot afford a good education for all the children and sometimes they even cannot afford primary education for all of the children. While families cannot afford it by themselves, state cannot provide free of fee education because of the high numbers of population and low GDP per capita (Todaro and Smith, 2011).

The lower GDP per capita is one more negative impact that high population growth has on economic situation. The problem is that the GDP per capita cannot grow as fast as the number of population in such areas does. It also means that there is less savings which is crucial for economic growth. Standards of living are decreasing, almost all sectors of social sphere are suffering from this (Ahituv, 2001).

One of the main ideas of the Malthusian theory is that population growth depresses wages because it negatively influences the supply of labour and thus decreases the wages - the "price" of labour. Depressed wages are the big difficulties for the poor population. Labor earnings are their main source of income because poor population is less likely to own some property or assets that provide them with some additional income. The argument is made that high population growth put pressure on the investment. As an economy tries to employ workers, the supply of savings as a source of investment decreases. Of course, defenders of this point of view claim that technological development can cope the high population growth, but Neo-Malthusians state that this advantage of technological growth is mostly the exception (Anderson, 2013).

It also proves that Neo-Malthusians consider that poverty is more than income deprivation. Fast population growth pushes the available capacities for basic human services as education, health, and food supply. So that these available capacities have to be spread over greater numbers of population so that the per capita supply of services is declined (Ahlburg, 1994).

High population growth almost always results in the growing inequality in the society. This is caused by the decreasing GDP per capita. But actually it does not only include the income per capita, it also has an effect on education, health care and food security (Todaro, 2011).

Population growth and distribution of the population have always been connected with the availability of clean water resources. So as far as the population growth fast the demand for clean fresh water growth too. During the last 50 years this demand was pushed a lot. The management of the world's water resources should be very correct to meet the growing demand pushed by growing number of population. At the same time, it is also important to prevent the further degradation of our available water sources and work on the cleaning up of the polluted waters. A great number of the world's population already has not stable or not enough access to clear safe water for every days life. And in some of the developing countries more than a half of the population has no access to such safe water resources. Shortages of the water resources and already polluted waters results also into lack of food security and possible health problems among the population that suffers from these shortages (Population Reference Bureau, 2016).

As far as the population growth demands more and more resources, the production of these resources becomes more and more dangerous for the environment. This problem is especially important in the most of developing countries because in such areas there is not enough investment and money to spend on more “green” methods of production while there is an endless need of production growth. Of course food production plays the most important role from all the resources.

In developing countries most agricultural methods are very destructive which leads to soil erosion and degradation and makes these lands not available for the future agricultural production. Agriculture produces about 25 percent of global greenhouse gas emissions, uses about 37 percent of lands, and requires about 70 percent of all freshwater non-salty water available on the planet (World Resources Institute, 2013).

The growing number of the population requires the growing mass of the vast resources of the world. This also crucially influences the environment. Not only the population number is important but also life style changes, urbanization, cultural and economical changes. The connection between high population growth and environmental problems seems to be very straight. The greater demand for resources also creates the greater number of waste produced by these used resources (Population Reference Bureau, 2016).

The figure below represents the Global environmental impact of agricultural production as a share of total impact. So it is visible how crucial can the effect caused by agriculture production be. Basically the larger the food demand is, the larger this numbers are (World Resources Institute, 2013).

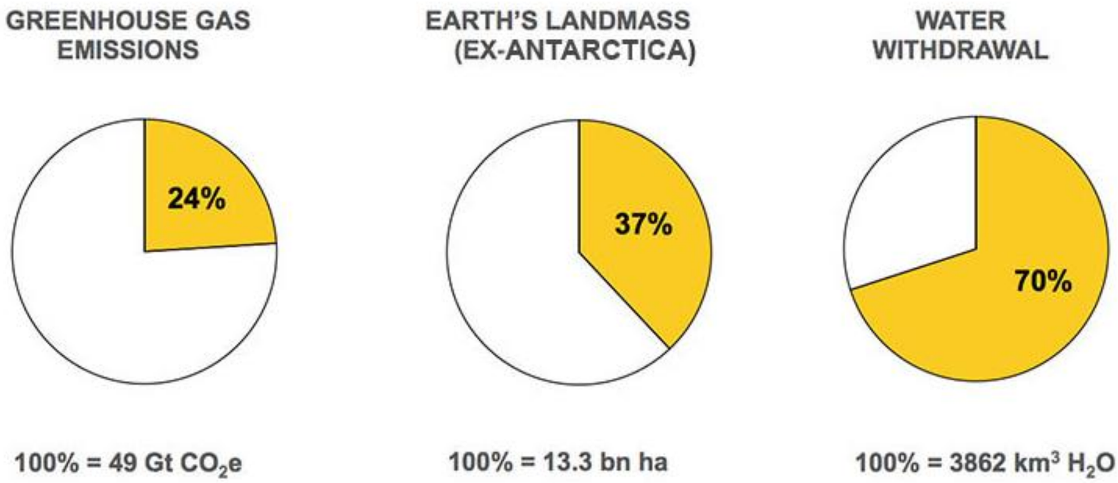

Fig. 2 Agriculture's Share of Global Environmental Impact
Source: World Resources Institute, 2013

There are two main views on the population influence on the environment. The one tells that high population growth leads to environment degradation. The second one states that high population growth stimulates technological growth and helps to find new ecology friendly ways of production. But many scientist in the ecological sphere believe that population growth just represents one of the list of the issues leading to ecological problems. Growing level of consumption supported by industrialization, difference in incomes and population distribution, wrong political decisions, low standards of living, and not enough technological growth all influence the destruction of the ecology. But even while the population growth is not the only factor there is a strong relationship between population growth and all the factors mentioned above which makes population growth crucially important (Population Reference Bureau, 2016).

All these consequences of too high population growth show the importance of some kind of rational population growth which will save the planet and will guarantee high standards of living to all the population.

Many people living in the poorest countries already suffer from severe food insecurity and the infrastructure's inability to sutisfy the basic needs of the citizens of the countries. The problem is that these countries have still one of the highest rates of population growth. In these countries the lives of more than a half of population strongly depends on the state og the agriculture. Sometimes this finishes in to the international migration when the population of developing countries emigrates to developed countries in hope to find a better life (Population Reference Bureau, 2016).

3.2 Food production and food consumption

In this subchapter the two main determinants of stationary state of population are reviewed: food supply and food demand. Food supply is presented by food production and food demand is presented by food consumption.

3.2.1 Food consumption trends

Evolution of the agricultural methods over the last 50 years increased the ability to provide food for all the population via growth in productivity, larger variety of foods and decreasing seasonal differences in production. The amount of the available food also grew as a result of growing incomes and decreasing food prices. All these led to a crucial evolution of food consumption over the last 50 years. Food consumption can be influenced by a wide variety of factors which includes the availability of food, the accessibility of food and food variety. All these factors otherwise can be influenced by another group of factors such as geography, demography, changes in incomes, urbanization, globalization, trade, religion, culture and consumer preferences (Kearney, 2010).

Data about the availability of the food groups on the national level can give a useful overview of the diets and the changes in diets that happened during the last 50 years. As a main variable used for analyzing the diets all over the world the food consumption per capita per day is used. This variable is usually calculated in calories. The data used for this variable is usually taken from Food Balance Sheets presented by FAO. The analyzes of this variables in the period of time from 1964 to 2030 shows that there was and supposed to be strong tendency of growth of calorie food consumption per capita per day. But still the values stay quite low for the less developed countries and regions (Vasileska and Rechkoska, 2012). All these data are provided in the table below.

Tab. 1 Global and regional per capita food consumption (kcal per capita per day)

Region	1964-1966	1974-1976	1984-1986	1997-1999	2015	2030
World	2 358	2 435	2 655	2 803	2 940	3 050
Developing countries	2 054	2 152	2 450	2 681	2 850	2 980
Near East and North Africa	2 290	2 591	2 953	3 006	3 090	3 170
Sub-Saharan Africa	2 058	2 079	2 057	2 195	2 360	2 540
Latin America	2 393	2 546	2 689	2 824	2 980	3 140
East Asia	1 957	2 105	2 559	2 921	3 060	3 190
South Asia	2 017	1 986	1 986	2 403	2 700	2 900
Industrialized countries	2 947	3 065	3 206	3 380	3 440	3 500
Transition countries	3 222	3 385	3 379	2 906	3 060	3 180

(source: Vasileska and Rechkoska, 2012)

The main drivers of food consumption can be listed as following (Kearney, 2010):

- income;
- urbanization;
- trade liberalization;
- transnational food corporations;
- retailing;
- food industry marketing;
- consumer attitudes and behavior.

Increasing incomes basically leads to the diets with more fat consumed. In such countries as Mexico and Brazil the obesity used to be a trend that showed that the person is reach. Now the situation changed and it mostly shows poverty. The growth of the incomes or decrease in prices led to the shift in consumption level of livestock products. While people with good education and high income may decide whether they want to eat healthy or not the poor part of the population don't have such variety of choices and have almost no chance to get some knowledges about healthy food. As an example situation in China can be overviewed. When per capita income increased there greatly after implementing the economic reforms in the 1970s, the consumption of high-fat foods rose crucially. If in 1962, a consumption of 20 per cent of total energy from fat was assuming the per capita GNP of $1475, by 1990, it was enough for GNP to be just about $750 to provide the same amount of fat consumed. The decreased level of poverty in China led to crucial changes in every day's diets which resulted in problems of proper healthy diets (Du, 2004).

Also as far as globalization process is speeding the traditional products which were consumed as the basic ones for hundreds of years moves to the second place all the global products of food industry becomes a routine in every country. Du, 2004).

The effect of income increase is also visible in the developed countries. But this effect is absolutely differs from the one watched in the developing countries. The researches says that this shift in the incomes results into better balanced healthy diets (Marmot, 2001). Over the past four decades this was changing the diets in the developed countries a lot (Lallukka et al., 2009). These changed diets led themselves to more healthy population which has its influences on the labour productivity, health care costs and many other factors (Kearney, 2010).

Another factor that will be reviewed is urbanization. It has a lot of effects. It should be mentioned that urbanization makes marketing easier, more accessable and cheaper. Urbanization gives to marketing such bonuses as easy access to modern tools of mass media, big channels of distribution, stimulating the growth of large supermarkets created by multinational companies and developing transportation systems which improves the availability of foreign suppliers and increases the part of imported products in the total food supply (Hawkes, 2006).

Another influence of the urbanization is connected to easier access to cheap fast food. Urbanization changes the lifestyles and together with this it changes the culture of food intake. Shortage of time that people living in the big cities suffer from changes their decision-making process about the food consumption. It basically makes them to decide for easy, cheap, fast and usually unhealthy food (Smil, 2000). The researches shows that consumption of livestock products was also higher for population of the cities (Mendez and Popkin, 2004).

The liberalization of trade also resulted in some changes of daily diets. This process changed the prices and availability of different product groups. While unhealthy calorie-rich products became cheaper most of the healthy products started to be more expensive. This resulted into changes in diets firstly for the poor population (Thow, 2009).

The liberalization of trade can lead to changes in the availability of some kinds of food by vanishing the trade barriers. The foreign investment in the food production sector can be influenced as well. Statistics show that the production of produced food increased in the developing countries after foreign investors got the access to these markets (Thow and Hawkes 2009).

Transnational food corporations (TFCs) play an important role in popularizing the fast-food as a culture, a market and a life style. This changes the culture of food in developing countries a lot (Hawkes, 2005). In developed countries where lifestyles dramatically to less active because of office work the consumption of fast food can easily lead to obesity (Popkin, 2006).

Another important factor influencing the food consumption trends to be mentioned is retailing system. The evolution of the retailing systems was so crucial that for the period of just 10 years the shift in this sector in the Latin American countries that it exceed the growth that happened during 50 years in the North American countries (Reardon and Swinnen, 2004). The retail chains and big supermarkets became main players of the agricultural sector in these countries. In the beginning of the 21st century supermarkets had 60% of all the sales of food in Latin American countries (Reardon et al., 2003). It means that supermarkets and big retailers can dramatically influence and change all the agricultural sector in this region what they actually did. Most of these retailers and supermarkets came from developed countries where they already had the markets under the control (Kearney, 2010).

This invasion of the global retail chains and supermarkets now happens in the East and South-East Asia (Reardon and Swinnen, 2004). So this retail systems influence the whole food supply system from the farmers to the final consumers. For most of the population these influences brought its benefits. As far as such retailer care a lot about the reputation and image of their companies they try to keep the quality and safety of food on the high level. Another big benefit of large retailers is competitive pricing. With the help of supermarkets the fresh products of livestock became available for poor population of some developed countries. For the urban consumers one big advantage of the supermarkets is convenience – they are close and the working hours are very convenient. But on the other hand, there are many negative sides of such big retailers. They help the global producers dominate the market with often unhealthy processed food that just leave the poor population no choice for consuming other types of food (Kearney, 2010).

So these two factors – the marketing and retail systems – went through a great evolution with the help of globalization process. And this evolution changed the process of food consumption a lot (Thow, 2009).

To show how crucial the influence of marketing and also government subsidies can be an example of beverage markets in the USA can be used. The consumption of the beverages changed dramatically during last 50 years. In the 50s of the 20th century American consumers bought more than 4 times more milk than all the carbonated soft drinks together. Nowadays the situation is wise versa. The Americans consume about 2.5 times carbonated beverages than milk. The first reason of this is strong marketing. These drinks became the part of culture. And another important support of the market of carbonated beverages came from strong government subsidies to the companies producing of corn syrup, which became more popular than normal sugar in production of these drinks (Putnam and Allshouse, 1999).

In the Asian and Latin American countries the advertisement and other succesful tools of marketing led to the increase in consumption of unhealthy overcooked food. The international companies and corporations came to these markets and used aggressive strategies for marketing because they saw an opportunity to use the increased disposable income of the population of these countries. The consumer decision about more healthy diet becomes very popular all around the world regarding to the increased availability of the information about healthy lifestyle. But still as the result of the aggressive distributing and marketing strategy consumers in the developed countries eat more than they need to. This has its consequences for the food supply as well as for the consumers (Kearney, 2010).

While a recommended daily consumption is required for survival, the real daily consumption of people living in the Western countries is much higher than any possible needs of a man could require. Researches showed that consumption in these countries is partially based on the expectations formed in the society and this expectations were more o less built by marketing (Schor, 1999)

The FAO's reports with built projections tell that a great increase in food demand is expected not only because of high population growth but also by the changes in daily calorie consumption per capita. This increase is projected to be about 70% (United Nations, 2016).

On the FAO Hunger Map 2015 we can see what regions are still suffering from hunger. Different colors picture the different percentages of population suffering of undernourishment. „*Undernourishment means that a person is not able to acquire enough food to meet the daily minimum dietary energy requirements, over a period of one year. FAO defines hunger as being synonymous with chronic undernourishment*" (FAO, 2017).

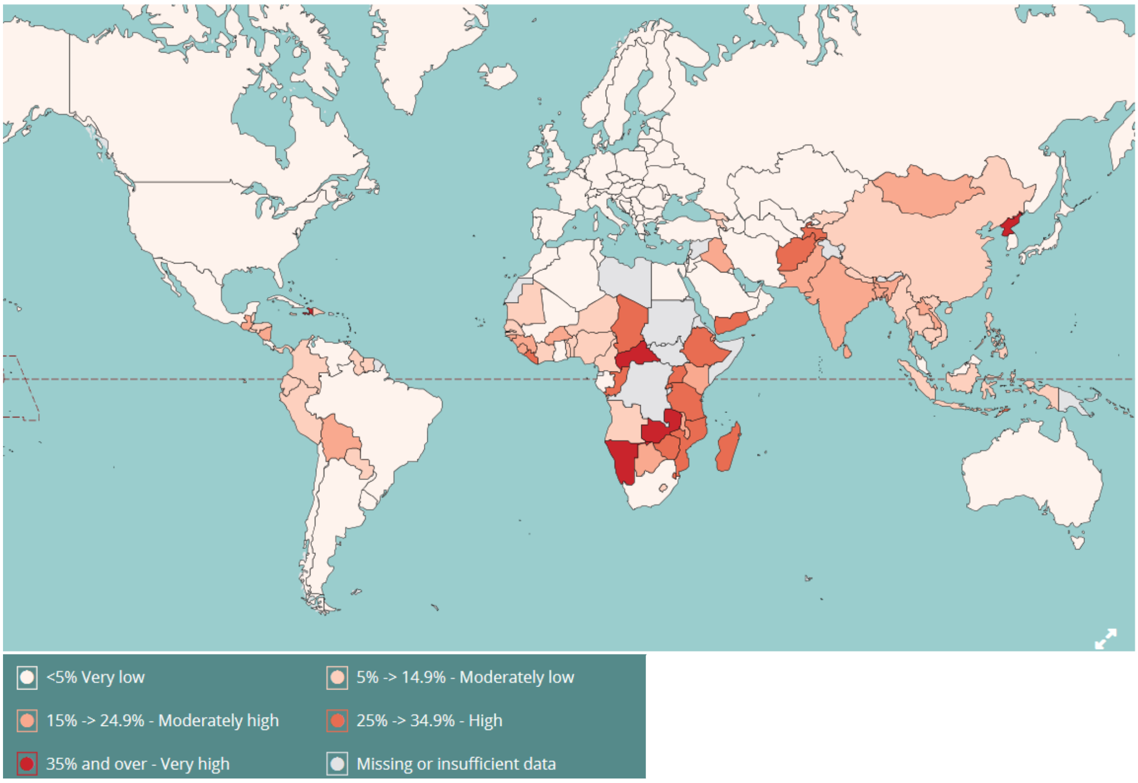

Fig. 3 FAO Hunger Map 2015
Source: FAO, 2017

Food consumption is sometimes characterized by food security or food insecurity. *„Food insecurity is a situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life".* (Population Reference Bureau, 2016). There are three main types of food insecurity according to FAO: chronic, seasonal and transitory. FAO states that food security is total only when all the population during all the time has full access without limitations to appropriate, safe and nutritious food which sutisfy their needs in calories and proteins and their choice of products for keeping the high level of activity and health (FAO, 2017). So it basically means that when food security exists food consumption is above or on secure level.

3.2.2 Food production trends

Food production is the base for food security. Even while the food security is understood as quite complicated definition including food availability, food access and etc., the starting point is however, food production that determines the base of food availability (Swaminathan and Bhavani, 2013).

The figure below represents the growth of the food production per capita in the different groups of countries. So it is visible that the growth was quite stable for almost all the countries, except transition countries, during last 50 years. Still there is a big difference in food liability in developed countries and less developed.

For some of the countries the growth of food supply per capita was more than 50%.

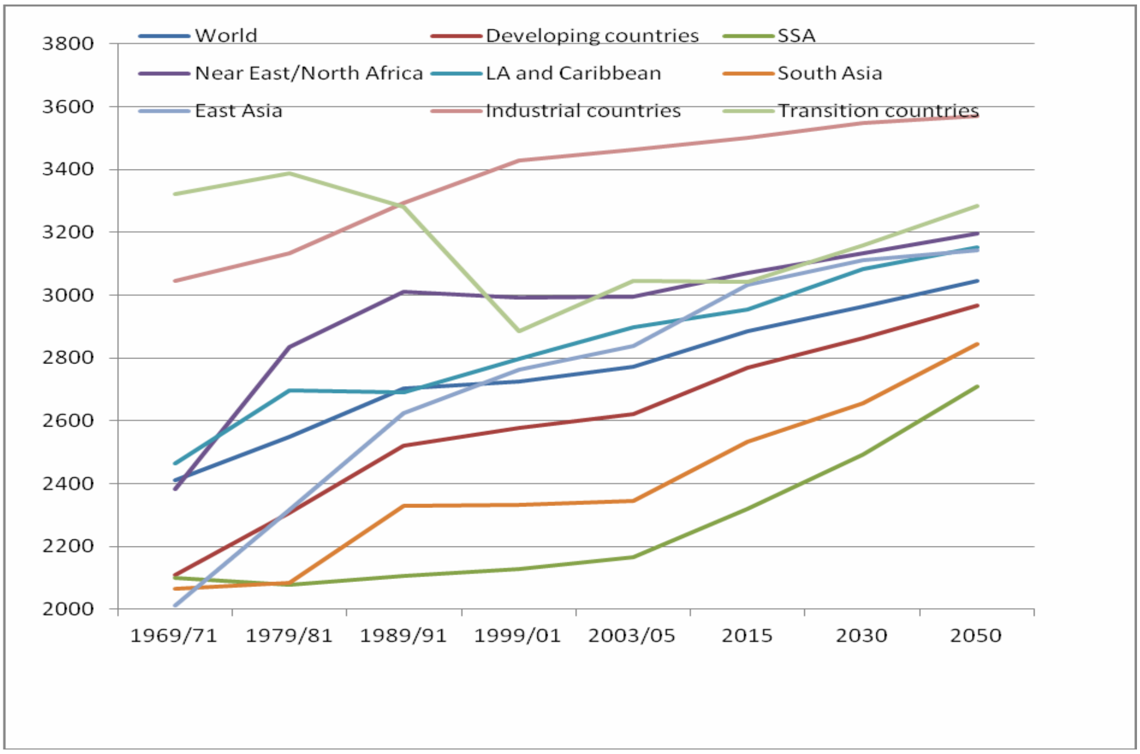

Fig. 4 Apparent food availability per capita
Source: FAO, 2017

Different researches proved that providing food supply for large population with increased disposable income for sure will require agriculture production to grow as much as 2 times at least till 2050. It means that agricultural production of crops should grow at least with the rate of 2.4% each year. Instead of this such main global leaders of consumption as maize, rice, wheat, and soybean now have the growth of production equal to only 0.9% to 1.6% each year which is much lower than what it is expected to be to feed the planet (Ray, Mueller, West and Foley, 2013).

It is important to remember that not all the production of agricultural sector is used for food production. The figure below represents the use of agricultural biomass worldwide. There are four main production targets for agricultural biomass (FAO, 2017):

- food production;
- animal feed;
- material use;
- energy use.

While first two categories are the sources of food security, the others two have nothing in common with food production.

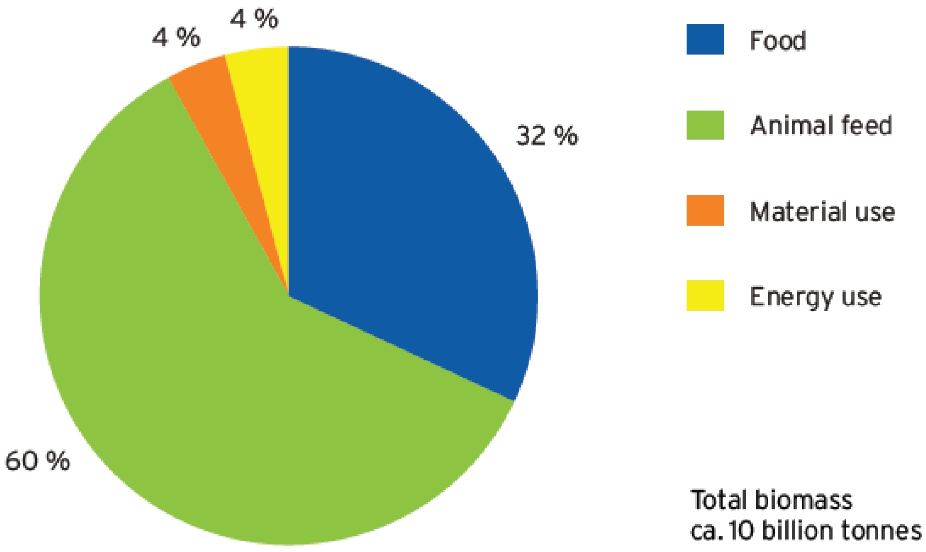

Fig. 5 Use of harvested agricultural biomass worldwide
Source: FAO, 2017

If there is not enough investment in the agricultural sector a lot of people will still suffer from undernourishment in the year 2030. This year is the year in which the Sustainable Development Goals (SDG) have to be achieved. These goals includes fighting with hunger and poverty first of all. As far as the water and land resources available for agricultural need are limited, the increase in food production should firstly come from improving the methods of agriculture and innovations in all the food production system. The statistics about the increase of production of the main groups of crops show that this increase in the productivity is still not enough (FAO, 2017).

The agricultural production will have to use more appropriate and stable food supply systems which guarantee saving land and water for the future usage and strongly decrease the input of fossil fuels that is responsible for the high green-house gas emissions. These changes will require higher investments in food supply systems and also it will require higher spendings on R&D which guarantees the growth of innovations, ensure enough production growth and provide new opportunities in fighting ecological problems. Not only food production systems need improvement, another important part of food supply – distribution channels – also need to be changed. Supply channels in the developing countries should better connect the farmers with modern food markets and large retail companies. (FAO, 2017).

The food supply was growing fast during the previous 30 years but even with this growth there is still large part of the population, especially in the developing countries, that constantly suffers from undernutrition. According to FAO, this number is about 800 million people while about 200 million of them are children (FAO, 2017). So it is questionable if this is a problem of lack of food production resources or if there are some other factors influencing this problem.

3.3 Theories of population

In this section main population theories are described. Rom the ancient times to the modern world, the problem of over population and resources limitation was popular among economists, sociologists, philosophers and demographers. A lot of different papers give a different look into the problem and give different solutions. Theories of population present the evolution of the economical and scientific thought in the population sphere.

3.3.1 Ancient philosophers on the population theory

The problem of population growth and the attempts to explain it were popular among the scientists, philosophers, writers and politicians since the ancient times. And it stays popular nowadays also.

Many of the ancient philosophers like Confucius (China), Kautilya (India), Ibn Khaldin (Arab), Plato (Greece) were interested in developing some ideas about population.

For example, Kautilya, who lived almost same time as Plato, wrote in his paper Arthashastra that ‘a large population is a source of political, economic and military strength of a nation’ (Kumar, 2005). The same opinion had the 14th century Arab historian Ibn Khaldin. He mentioned in one of his papers that the increase of dense population is mostly advantageous to the stability and growth of imperial power (Kumar, 2005).

Little bit different opinion about population problem had Chinese philosopher Confucius. He thought that there should be some balance between population and environment. That means that, in his opinion, unchecked growth of population could harm. Confucius was the first philosopher who wrote about the idea of optimum population number. It was quite innovative while the earliest thinkers in Greece supported the unlimited growth of population (Tang, 1995).

3.3.2 Malthusian Theory

In this section an overview of Malthus Theory of Population growth is presented. The both sides of opinions are described – the Malthus’ ones and his opponents which gives more critical view of the problem.

Thomas Robert Malthus and his ideas

Thomas Robert Malthus was the first economist to design a logical theory of population. He was mostly following all the principles of classical political economics. But he was more concentrated on the explanation of demand while other followers of the classical political economics were more interested in explanation of the supply. And as a main factor of demand Robert Malthus saw people or the population of the country itself. So he wanted to explain the existing and strict, in his opinion, relationship between economic factors and demographic factors. His views regarding the problem of population were presented in his well-known book, *Essay on the Principle of Population* (1798). In this book he used empirical data which supported his theory.

One of the most important ideas which were proposed by Malthus in his book was the principle that human population grows exponentially while the production of food on Earth grows arithmetically. It means that population doubles with each cycle while food production increases much slower by adding the repeated amount in some interval. Malthus concluded that the evolution of the amount of food produced around the world was same as in the arithmetic progression (1, 2, 3, 4, 5, 6, 7, 8, 9, and so on). But the growth of population could be presented like geometric progression (1, 2, 4, 8, 16, 32, 64, 128, 256 and so on). So after analyzing these data Malthus made a conclusion that if these scenarios stayed the same in a visible future there would be a situation when humans would have no food resources even to survive on the planet (Malthus, 1807).

One of the most important concepts on which the Malthusian Population theory is based is the Population Trap model. This model shows the connection between population growth and economic development. It also explains what can be the consequences of situation when population growth rate exceeds income growth rate.

So some possible situations can be described including these factors. One of the possible situations is when the income growth rate is higher than population growth rate. This situation is positive because income per capita also grows. But when income per capita is really small, the population growth rate is decreasing because people cannot afford even satisfying of basic needs. The crucial moment is when the minimum level of income per capital was reached. After this moment the income per capita is decreasing because the population grows faster that income growth rate (Todaro and Smith, 2011).

The Malthus' theory can be described graphically if we take the population growth as geometrical progression and food supply as arithmetical progression. The Figure represents two lines. The first line (green) shows population growth during time. We can see that it increases at a geometric rate. The second line (yellow) is a production of food line. And we can conclude that it growth arithmetically. The point "T" shows the time when food supply reaches its maximum in satisfying the needs of population.

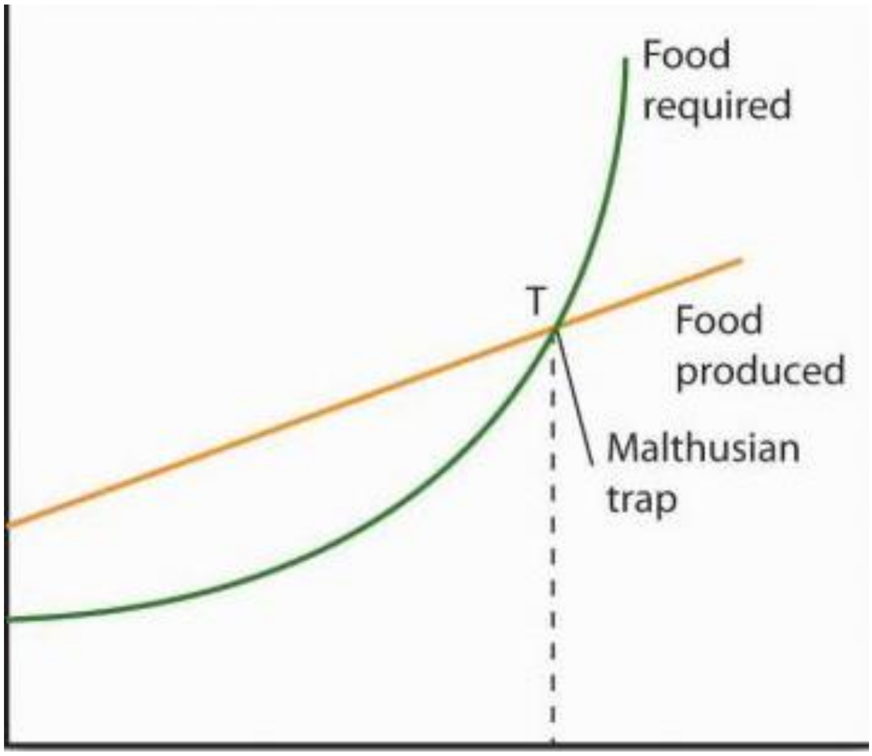

Fig. 6 Population Trap
Source: Summarizing of Malthus' theory, 2008

It is an interesting fact that Thomas Malthus watched people firstly like consumers. Before the appearing of his theory the growth of the population was always expected to have some positive influence. As it was expected that the growing number of workers can lead to the economic growth.

In his opinion, special system of control on population growth is needed.

The economist made some calculations according to the world population numbers in the beginning of the 19th Century. Malthus supposed that possibly population would increase to 256 billion during next 200 years while all the food produced by that time would be enough for not more than nine billion humans. That is why he suggested various controls on population growth, which were categorized by him as "preventive" and "positive" checks.

As one of the most important preventive checks Malthus named "moral restraint", which meant that every man had to be attached to one woman to marry her later but only when he would be ready to support a family. In his opinion, it could lead to smaller families. Malthus knew that this can cause illegitimate births but he was sure that the control on population growth is a bigger problem.

As positive checks the scientist meant all the possible ways to shorten the lifespans of people. Malthus mentioned some factors that can cause less resistance to diseases, such as poverty, bad working conditions, and some factors that can cause death itself, such as diseases, wars and famines (Hayami and Godo, 2005).

Criticism of Malthusian Theory

As some negative points of the Malthus`s theory we can mark the fact that he had a look on the problem of population without any connection to the existing way of production and the present level of the development of the society. He thought that "the principle of population" would stay the same forever. The author thought that with every year land used for production of food will be less and less productive. But Thomas Malthus didn't realize that the factors of production which were used on the land would change a lot in the future years same as the methods used in the agriculture. Which means that he didn`t take into account that the technological progress and the whole progress of the society can lead to such a great improvement in capital growth rate that income per capita would be anyway growing even while population growth is high (Todaro and Smith, 2011).

The economist also states, for example, that the number of population of the North America almost doubled during last 25 years. But actually this fact took place only in the exact historical period and was mostly affected by immigration while Malthus claimed that it was a result of childbirths. It means that the statistical data used by the scientist was not proper or were not interpreted correctly.

Also some new empirical evidences were not on the Malthus`s side. During two centuries the population grew by six times, while standard of living changed positively due to increase in production of food and its consumption all around the world (Sen, 1999).

So it seems that Thomas Robert Malthus was looking for the ideal solution of the problem of overpopulation but not in the economic sphere. He tried to find the way to decrease the demand not even thinking about the ability of increasing of the supply (Malthus, 1807).

Karl Marx didn`t support Malthus`s ideas. He thought that famine was caused by the unequal distribution of the wealth and its accumulation by capitalists. So, in his opinion, the population growth wasn`t responsible for it. Population wellbeing depends on economic and social organization of the society. But Marx's ideas also were not ideal. He stated that the production of food would not increase rapidly. Latter when the new technology began his ideas were criticized (Gimenez, 1973).

3.3.3 Neo – Malthusians Theory

Thomas Robert Malthus set the initial stage for discussing the population problem. His theory inspired many other scientists, such as Samuel Van Houten, Paul Ehrlich, Julian Simon, Lester Brown, Garrett Hardin, Norman Myers and Barry Commoner. These theorists carry on this topic to the second half of the 20th century.

The term "Neo-Malthusianism" was firstly used in 1877 by Dr. Samuel Van Houten. He was one of the vice-presidents of the Malthusian League. The main idea of the school still was the same – the control on population growth. There were two main differences between the Neo-Malthusianism and classical Malthusian theory. The first feature is the concentration on birth control only. And the second difference is that the Neo-Malthusians counted the Malthusianism working class as the main factor of the population growth.

According to the Neo-Malthusians, the better living conditions could give the poorest population the reason not to have so many children. The studies of the school were quite highly supported by the elites of the community. The elite was interested in control under the high population growth because they were afraid of future conflicts of interest with commoners.

The Neo-Malthusians had quite strong political influence. They had different forums, such as the British Malthusian League (1919) and the Sixth International neo-Malthusian and Birth Control Conference (1925), where they discussed their ideas and insisted on implementing some restrictions of birth rate. They were sure that it was the only way to improve the standards of living and provide the defense for the country (Ledbetter, 1976).

Paul Ehrlich, a biologist, whose book The Population Bomb was published in 1968, was one of the most famous Neo-Malthusians. In his opinion, the population growth rate was exceeding the growth of the agriculture and the abilities of the renewal natural resources of the planet. The scientist stated that the future demographic disaster is predictable (Aligica, 2009). His predictions were quite pessimistic. Here are some of his sentences: "The battle to feed all of humanity is over", "In the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash programs" (Ehrlich, 1968). He even mentioned the possibility of the thermonuclear war caused by many geopolitical crises because of severe global food problem. Ehrlich's population theory consisted of three main elements: a rapid rate of change, a limit of some sort, and delays in perceiving the limit.

The Ehlich’s ideas were mostly criticized because they were taken as a repetition of Malthus’ ideas. But another important Neo-Malthusian, Julian Simon, didn’t agree with some conceptual points of his paper. Simon found the definition of limits explained by the Ehlich doubtful.

In the 1970s, Julian Simon wrote his two main papers on population theory. The first one, The Economics of Population Growth, was published in 1977 and the second one, The Ultimate Resource, – just four years later. In his books Simon criticized the simple explanation of the relationship between the economic and population growth given by Paul Ehrlich. He also thought that the great impact of the population growth on the existing resources was overvalued. The main idea of Simon’s studies was based on his sureness that Ehrlich was wrong about the limits of the availability of the resources. Simon moved his theory in another direction.

In his opinion, the limits existed only in people’s minds. He believed that the growing population would have enough ideas about improving the infrastructure and the environment. So that it would be possible to have enough food, housing and other goods to satisfy all the basic human needs. Simon also criticized the empirical data which were used to design most of the population theories. He believed that the time frames of these theories were too short to be useful (Aligica, 2009).

If we can study the population problem as an equation with population on one side and all the needed resources on the other side. We can conclude that most of the Neo-Malthusian ideas had one common feature. All the problems, according to the Neo-Malthusians, are expected to arise on the population side of this equation. It means that they saw the solution of the population problem only in restricting of the population growth, while the increase of the production of food was not counted as another opportunity.

3.3.4 Ester Boserup Population Theory

Ester Boserup was a famous economist whose studies were mostly dedicated to economics and agriculture. She is famous for her work as a consultant for the United Nations and her studies of the undeveloped and developing countries and its agriculture. This work helped her to formulate her own population theory. Boserup's theory explains the relationship between the growth of population and the production of food.

One of the most famous papers of Boserup is The Conditions of Agricultural Growth: The economics of agrarian change under population pressure. It was published in 1965. In this book Ester Boserup represented the opinion opposite to the Malthus' one. While Malthusians conclude that the growth of the population is limited by the resources, Boserup believed that the production of food can grow with the population growth.

Sixteen years later Ester Boserup finished another her important book: Population and Technological Change: A Study of Long Term Trends. In that book she developed some of her previous ideas about the population growth and innovations in agriculture. She believed that any society would search for improvement of existing production technologies in case of great need. It means that Ester Boserup in her own way supported the population growth and found it useful. In her opinion, large population brings its benefits, such as progressive technologies, urbanization, labor specialization, economies of scale and etc.

One of her famous statements was "Necessity is the mother of all invention". She thought that the need to feed more and more people could motivate humanity to improve their technologies and to find new opportunities of food production. To explain this idea, she used a term "agricultural intensification".

To support her ideas, she used some empirical data from developing countries. For example, she wrote about the production of rice on the Philippines, which increased more than twice in just 20 years (1966-1986). Also as a proof of her theory she used examples of already invented tools and methods of increasing the productivity of agriculture.

In the latest years of her work she tried to explain the existing relationship between the growth of population, structure of families, the role of women as the participants of production, economic development. She continued to insist on the positive role of the high level of fertility as an accelerator of the new agricultural techniques and innovations.

So Boserup's population theory is a model that explains the ability of continuous population growth. Her ideas inspired many new topics for the research in spheres like anthropology, agriculture, economics, demography and sociology (Marquette, 1997).

3.3.5 Demography

It is extremely important to understand the main ideas and formulas of the demography study to proceed a modern analyzes of population size and structure. The demographical science is the base for any population research.

Demography can be simply subscribed as "*the study of population structure and change*" (Hinde, 1998). If we explain demographical science in more details we can use the definition written by Siegel: "*the study of the size, geographic distribution, age-sex structure, and socioeconomic composition of populations and the factors that affect changes in these dimensions of population, namely, fertility, mortality, and migration*" (Siegel, 2008).

The main objectives of the demography are the future numbers and components of human population. Three main factors are valued as most important in estimation of population indexes. They are fertility, mortality and migration (Hinde, 1998). These three factors estimate changes in population growth and structure, including the ways people inhabit the Earth and use its sources.

Another scientists explain the demography as a combination of 5 factors that determines main population trends (Siegel and Swanson, 2009):

- population size,
- population distribution,
- population composition,
- population dynamics,
- socio-economic determinants and consequences of population change.

3.3.6 Theory of demographic transition

Another very important population theory is the theory of demographic transition. The term demographic transition was firstly used by Warren S. Thompson (1929), and later on by Frank W. Notestein (1945). They used this term to describe a historical process of change which includes the trends in births, deaths and population increase that happened mostly in the European societies. This kind of demographic evolution started for most of the countries in the later 18th century.

The theory of demographic transition can be simply explained as a theory which tries to analyze and identify general laws by which population numbers grow and change its structure with the influence of industrialization. It analyzes demographical data and according to these data concludes that there was a change from a high fertility and high mortality to a low fertility and low mortality when a society developed into a dominant urban, industrial and literate society.

Usually this change is described as three-phase process. First phase is when the decrease in deaths happens while the fertility is still the same. Second stage takes place when fertility decreases to match mortality. And the last phase means that socio-economic changes in a structure of the society happen parallel with demographic changes in the society.

Birth and death rates decrease the same way which leads to population increase equal to zero. When describing the pre-industrial societies, the theory of demographic transition states that there is a small population growth because of high death rate and also high birth rate.

The great progress in easy-accessible medical technologies moved a lot of non-industrial countries to the second stage of the demographic transition. But most of these countries were not ready to move to the third phase. As the result of this the population of these societies was suffering from hunger and poverty. Unfortunately, some of these countries are fighting these problems till now (Kirk, 1996).

Still for the most of the countries in the world the stages of demographic transitions are quite different. Undeveloped and developing countries still experience quite high population growth but high developed countries which achieved the third stage of demographic transition are in absolutely different situation. In some countries, especially in Eastern and Central Europe the population growth is equal to 0 or even negative for quite a long time already (Birdsall and Kelley, 2001).

While developed countries finished the transition process already, the developing countries in the regions like Africa and Asia are still in the beginning of their path. ''The more the country is developed, the further it has progressed through the transition'' (Birdsall and Kelley, 2001).

One more important demographist, Glenn Trewartha, thinks that differences of countries in economic transition are the results of the dual nature of human beings. And because of this, in his opinion, even nowadays different societies are on the different transition stage. According to Glenn Trewartha, the cultural side of people differs a lot in the most societies and exactly this factor prevents some countries from moving to the third stage (Graham, 2004).

According to the theory of demographic transition the structural changes in human population is just an evolution from one equilibrium with high death and birth rates to another with low ones. Some other scientists, such as Coale and Hoover, wrote about the influence of economic development and moving to industrialized society in the demographic changes.

So the theory of demographic transition gives quite a full description of the world's demographic evolution. Even while the research is based on the empirical evidences of the Western countries, the main ideas can be used to analyze almost any country in the world (Kirk, 1996).

4 Methodology

In this chapter the methodology of the research is presented. As far as the suggested aim of the diploma thesis is to estimate the calorie model and the timeframe of the stationary state the methodological part includes formulas and equations used for recalculating of values into calories. Ways of determining the real global food demand and real food supply in calories are also analyzed here.

4.1 Stationary state of population

The global understanding of the stationary state of population can be explained as an equilibrium of food consumption and food production. So if we talk about stationary state of population, under this we mean the situation when the population reached its maximum level guaranteeing global food security. This situation is explained by FAO (Food and Agriculture Organization of the United Nations) as following: *"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" (FAO, 2017).

The FAO's understanding of food security is quite complicated. Because it includes not only the production of enough amount of food but also the access to this food. The classics saw just one side of this problem. Classical understanding of stationary state of population takes into the account only the food availability. So in this paper the estimation of the possibility of reaching classical stationary state is taken as the base of the research. This stationary state means that there is just enough food for everybody and there is no food available for any additional person. So the production of food is equal to population needs.

It is also important to understand that reaching of the stationary state means that the highest population level that guarantees food security in its classical understanding was achieved. So if the population growth rate would continue to increase faster than the food production technological growth rate, population would be starving. In this case, two situations are possible. First one is the situation when the technological growth rate (technological progress) is growing faster than the population growth rate. In this situation the stationary state cannot be achieved because the amount of food would be always bigger than the need of population. Another situation is when population growth rate growths faster than technological growth rate. If it happens the stationary state can be achieved and the greater is this difference the faster it can be achieved. Of course firstly we need to know the present situation.

4.2 Calories as the main denominator

To have the ability to calculate the possible stationary state we firstly need to understand what quantities can be used to estimate supply and demand of food. So as supply we commonly understand the global food production and as the demand the global needed food consumption. Global food production is the total amount of all food produced all over the world. Global food consumption is the total amount of food which is needed to feed all the people around the world according implying the conditions of the food security.

For estimation of the possible stationary state I chosen the following indicators as crucial for equalizing of food supply and demand: total population, total crops production in tons, animal food production in tons, animal food production in tons, calories needed per person per day. The following table describes these indicators in more details. These indicators will be used for creating the data sets for the practical part of the research.

Tab. 2 Indicators of food supply and demand

Indicator	Description	Driving forces
Total population	The sum of global population (disaggregated in the model into 81 age cohorts and by gender)	Total fertility rate, life expectancy at birth.
Total crops production in tons	The sum of all crops production, in physical quantity(tons).	Capital, labor, soil nutrients, water availability, health, education, research and development, energy availability.
Animal food production in tons	The sum of all animal production, in physical quantity (tons).	Availability of pasture area, availability of animal feed products.
Calories needed per person per day	The amount of calories consumed per person, per day.	Population structure, human needs

So all these indicators should be included in the research to get the full picture of the problem.

So as common determiner of food demand and food supply calories can be used. In this case the supply is represented by calories that we are able to produce at our technological level from disposable land that is used in agriculture. Demand can be calculated then as all the calories that have to be consumed by all the people to support the global level of food security.

To estimate the stationary state we also should add the time and growth rate constraints.

So the needed average amount of calories per person per unit of time is consumption needed – c_N . The total amount of calories which is needed to be consumed in time t can be expressed as

$$L(t)c_N \tag{1}$$

where $L(t)$ is the total population in time t.

The global food supply per unit of time is represented by a_T. This value represents food supply which could be provided by using all the agricultural land only for food production. The total amount of calories which could be produced in time t by using all the agricultural land used for food production can be expressed as

$$A(t)a_T \tag{2}$$

where $A(t)$ is the level of the technological growth (food production technological growth) in time t (Machay, 2012).

4.3 Equation of stationary state

The model and formula of the stationary state estimation should be used under some assumptions:

Assumption 1: Suppose the food – more precisely calories – is equally distributed among the world population.

Assumption 2: Assume the population and food production level grow at constant rates which are positive ($n > 0; g > 0$).

Assumption 3: All the agricultural land is used for the food production.

Assumption 4: The age structure of the population is stable.

The first assumption is needed because in case calories are not distributed equally it is impossible to take the values of food supply and food demand per capita as an exact number. The third assumption is used because in case the stationary state comes all the produced biomass will be firstly used for food production.

The consumption surplus (c_s) – or how many people can be fed from contemporary calories share of one person – is expressed by a fraction of (1) and (2):

$$c_s = \frac{A(t)a_T}{L(t)c_N} \tag{3}$$

So following formula describes consumption surplus level at any time t:

$$c_S = \frac{e^{gt}\, a_T}{e^{nt} c_N} = e^{(g-n)t}\, \frac{a_T}{c_N} \tag{4}$$

As far as stationary state is the situation when further possible population growth is not possible because of food limitation, the supply and demand should be the same. In this situation there is no consumption surplus and $c_s = 1$.

Same equation as (4) but assuming $c_s = 1$:

$$1 = e^{(g-n)t}\frac{a_T}{c_N}$$

$$\frac{c_N}{a_T} = e^{(g-n)t}$$

$$\log c_N - \log a_T = (g-n)\mathrm{t}$$

$$t_P = \frac{\log c_N - \log a_T}{g-n} \quad (5)$$

This is the crucial formula to be used in this paper. In this case equation (5) represents the estimation of stationary state, where $t_P$is the time when the population needs of food and global food production will meet each other. So t_P is the main indicator to be calculated in this paper. Basically if $t_P < 0$ means that stationary state cannot be possible in future. So t_P must be large than 0 to achieve the stationary state (Machay, 2012).

4.4 Data sets used for analysis

For this diploma thesis the data provided by different international organizations (FAO, USDA, UNPF) were used. In these section data sets which are used to calculate the main variables of the stationary state equation are presented. As a unit of time one year will be taken for all the variables. As a basic year for all the variables the year 2016 will be taken. Most of the data sets will be changed in the practical part to make them appropriate for the aims of the research.

4.4.1 Data for estimation of an average amount of calories needed per person per unit of time

Firstly, the average amount of calories per person per unit of time (c_N) needs to be found. This average amount of calories per person represents the minimum amount of calories input according to energy requirements. Energy requirement is the amount of food energy needed to balance energy expenditure in order to maintain body size, body composition and a level of necessary and desirable physical activity consistent with long-term good health. The recommended level of dietary energy intake for a population group is the mean energy requirement of the healthy, well-nourished individuals who constitute that group (FAO, 2017).

As far as all the requirements are given for the different age groups of population for estimating the average amount the weighted average will be found. For calculation of this amount two main data sets are needed:

- Recommended minimal daily amounts of daily calories input. This data set will include the amounts of calories recommended for different age groups.
- World population by age.

The tables below represent the minimal amounts of calories which are recommended as daily input for different age groups (FAO, 2017 and USDA, 2017).

Tab. 3 Reccommended minimal daily input in calories – Infants and children

Infants and children	
Age	**Calories**
3–6 months	700
6–9 months	810
9–12 months	950
1–2 years	1 150
2–3 years	1 350
3–5 years	1 550

Source: Summarizing of the data presented by FAO and USDA

Tab. 4 Reccommended minimal daily input in calories – Children

Children	**Boys**	**Girls**
Age	**Calories**	
5–7 years	1 850	1 750
7–10 years	2 100	1 800
10–12 years	2 200	1 950
12–14 years	2 400	2 100
14–16 years	2 650	2 150
16–18 years	2 800	2 150

Source: Summarizing of the data presented by FAO and USDA

Tab. 5 Reccommended minimal daily input in calories – Adults

Adults	Male	Female
Age	Calories	
18–20 years	2 800	2 200
21–25 years	2 800	2 200
26–30 years	2 600	2 000
31–35 years	2 600	2 000
36–40 years	2 600	2 000
41–45 years	2 600	2 000
46–50 years	2 400	2 000
51–55 years	2 400	1 800
56–60 years	2 400	1 800
61–65 years	2 400	1 800
66–70 years	2 200	1 800
71–75 years	2 200	1 800
76+ years	2 200	1 800

Source: Summarizing of the data presented by FAO and USDA

The following tables include the statistical data about the world population by age and gender. The data set was changed to suit the previous table so that different ages were accumulated into groups with the same calories intake.

Tab. 6 World midyear population by age and sex 2016 - Infants and children

Infants and children	
Age	Population
under 1 year	131 517 032
1 year	129 629 099
2 years	128 314 774
3–4 years	253 925 848

Source: Modification of the data by United Nations,2016 and United States Census Bureau, 2017

Tab. 7 World midyear population by age and sex 2016 – Children and adults

Age	Male population	Female population
5–6 years	129 591 760	120 808 842
7–9 years	191 728 279	178 583 708
10–11 years	125 158 538	116 511 019
12–13 years	123 611 481	115 072 594
14–15 years	122 657 122	114 172 615
16–18 years	183 431 337	170 977 830
19–25 years	427 565 898	402 030 085
26–45 years	1 073 108 853	1 042 043 391
46–50 years	226 560 452	224 028 966
51–65 years	493 513 224	512 850 361
66+ years	257 008 694	323 364 804

Source: Modification of the data by United Nations,2016 and United States Census Bureau, 2017

These tables will be used to calculate the weighted average amount of calories per person per unit of time. In this case the following formula of the weighted average can be used:

$$\bar{x} = \frac{w_1x_1+w_2x_2+\cdots+w_nx_n}{w_1+w_2+\cdots+w_n} \quad (6)$$

where $\bar{x}$ is a weighted average, w is relative weight and x is value. So in this case x_n is recommended minimal input in calories per person per unit of time, w_n is world midyear population by age and sex and $\bar{x}$ is average amount of calories per person per unit of time.

4.4.2 Data for estimation of total food supply per unit of time

The second important variable to be estimated is the total food supply per unit of time is represented by (a_T). As a unit of time year is taken again. There are two possible ways of calculating of this variable:

1. The data of world food production per year in tonnes should be recalculated to get the world food production in calories by using average calorie values of different categories of agricultural production.
2. The data about food supply per capita per day.

It is better to calculate it using both methods and to decide after which one is preferable.

For these both methods 2 main data sets and 2 values will be used:

1. World food production
2. Average calorie values of the main groups of agricultural food production items by 1 gram

3. The world total population
4. Food supply per capita per day in calories

So firstly, the data sets for the first method will be presented. For the first method world food production in tonnes and average calorie values of different agricultural items by 1 gram should be reviewed.

The data about world food production of food in tons should include following categories of agricultural products (FAO, 2017):

- wheat;
- coarse grains;
- rice;
- oilcrops;
- meat;
- dairy;
- fisheries.

The table below represents the global production of these seven main groups in tonnes in 2015 - 2016. Also the agricultural production in whole and production of the items which were used in future food production.

Tab. 8 World food production 2015 - 2016

Product of agriculture		**Amount in million tonnes**
Wheat	Whole production	734.1
	Food	491.4
Coarse grains	Whole production	1 303.6
	Food	200.6
Rice	Whole production	490.1
	Food	399.7
Oilcrops	Whole production	532.7
	Food	409.6
Meat	Whole production	319.6
	Food	
Dairy	Whole production	802.8
	Food	
Fisheries	Whole production	171.0
	Food	149.4

Source: Summarizing of the data presented by FAO, 2017

To recalculate the data from the above table into calories information about average calorie values of these items is needed. These values averages are presented in the next table.

Tab. 9 Average calorie values by 1 gramm

Product of agriculture	Amount of kcal/g
Wheat	3.391
Coarse grains	3.2
Rice	3.6
Oilcrops	6.06
Meat	1.43
Dairy	0.6
Fisheries	0.8

Source: Summarizing of the data presented by FAO, 2017

For the second method of calculation of the calories supply per capita in the unit of time the data about food supply per capita in calories and the number of population will be used.

According to FAO, calorie supply per capita is the amount of all food available for consumption, measured in kilocalories per capita per day. This figure is reached by dividing the total available food supply for human consumption by the population. These figures can be taken as an average supply available for consumption (FAO, 2017).

There are various possible ways to define food supply and, in fact, various concepts are in use. The elements involved are production, imports, exports and changes in stocks (increases or decreases). There is no doubt that production, imports, and decreases in stocks are genuine supply elements. Exports and increases in stocks might, however, be considered to be utilization elements. Accordingly, the following possibilities exist for defining "supply":

1. Production + imports + decrease in stocks = total supply.
2. Production + imports + changes in stocks (decrease or increase) = supply available for export and domestic utilization.
3. Production + imports - exports + changes in stocks (decrease or increase) = supply for domestic utilization.

In recent years the third concept has been adopted when preparing and publishing food balance sheets in order to identify the quantity of the commodity in question which is available for utilization within the country (FAO, 2017).

Unfortunately, the only trusted source of this information is FAO and it only presented the latest numbers for the year 2013 till now. In this case this data will need to be changed later with the usage of the food production growth rate to get the data for the year 2016.

The data were taken from FAO Food balance sheet. FAO's food balance sheets present a comprehensive picture of the pattern of a country's food supply during a specified reference period. The food balance sheet shows for each food item i.e. each primary commodity availability for human consumption which corresponds to the sources of supply and its utilization (FAO, 2017). So, according to FAO's Food Balance Sheets, food supply per capita per day in calories in 2013 was 2884.

So this data show how many calories are produced per person per one day. As the unit of time same as in the previous case one year will be taken. These data need to be multiplied by 365. So to know the food supply in calories per person per year 2016 following steps will be done:

- the total food supply in calories will be defined for year 2013;
- using the growth rate of food production the total amount of calorie supply for 2016 will be calculated.

After this the last step is to calculate what this supply could be if all the agricultural biomass produced was used for food production. For this the value of total food supply should be expanded for the amount of the agricultural biomass used for material use and energy use. So this number will be taken as percentage. According to FAO's data the production of material and energy represents 8% of the all biomass production of agriculture.

4.4.3 Data for estimation of the grows rates

The next step of collecting data for this research includes finding the population and food production grows rates - n and g. It is important to remember that according to the assumptions presented in the previous subchapter both these levels of growth are positive and grow at constant rates.

So the first value to be found is n. It represents the population growth rate. Assuming it is constant, the average population growth rate should be calculated. For this reason, the world total population number for last 11 years will be used.

Tab. 10 World population in millions 2007 - 2016

Year	Total population in millions
2006	6 540.3
2007	6 615.9
2008	6 749.7
2009	6 829.4
2010	6 908.7
2011	6 974
2012	7 052.1
2013	7 162
2014	7 244
2015	7 349
2016	7 433

Source: United Nations Population Found, 2016

The last variable which is crucial for the formula of the stationary state to be defined is the food production grows rate or technological growth rate (g).

According to the FAO the world growth in agricultural production in percentage per annum for the years 1997 – 2015 was 1.6. It is possible to take this number as average food production technological growth rate and use it in this research. It means that every year the agricultural production growth for 1.5% in relationship to the previous year. So the value of the food production grows rate for this research will be taken as 1.6 ($g = 1.6$) (FAO, 2017).

Most of these data sets presented in this subchapter still need to be recalculated or changed to fit the research needs. Only the last value of the food production grows rate will be taken in the given form.

5 Practical part

In this chapter all the calculations will be made according to the methodology. Collected data sets presented in the previous chapter will be changed, modified and recalculated to determine the values of the main variables needed for the estimation of the stationary state. After the values will be put in the main formula and calculated.

5.1 Finding the main variables

In this subchapter the values of the main variables of the stationary state equation will be calculated. This will be done by using of the data sets presented in the Chapter 3. These datasets will be changes and recalculated in order to satisfy the needs of the research.

5.1.1 Minimal recommended calorie input per person per unit of time

Firstly, average minimal recommended amount of calorie input per person per unit of time (c_N) will be calculated. To calculate this amount two data sets presented in the previous chapters will be used:

1. Recommended minimal daily amounts of calories input
2. World population by age groups

These data can be used to calculate the weighted average amount of minimal calories input per person per unit of time so that there would be no need to use more than one variable.

As a unit of time a year will be taken. So there is a need to estimate minimal recommended calories input per person per year. The table below represents recalculated and modified data about calories input.

Tab. 11 Reccommended minimal yearly input in calories - Infants and children

Infants and children	
Age	**Calories**
under 1 year	295 650
1 year	419 750
2 years	492 750
3–4 years	565 750

Source: Summarizing of the data presented by FAO and USDA

Tab. 12 Reccommended minimal yearly input in calories – Children and adults

Age	**Calories**	
	Male	**Female**
5–6 years	675 250	638 750
7–9 years	766 500	657 000
10–11 years	803 000	711 750
12–13 years	876 000	766 500
14–15 years	967 250	784 750
16–18 years	1 022 000	784 750
19–25 years	1 022 000	803 000
26–45 years	949 000	730 000
46–50 years	876 000	730 000
51–65 years	876 000	657 000
66+ years	803 000	657 000

Source: Summarizing of the data presented by FAO and USDA

So the data about the recommended minimal yearly input in calories and total population numbers will be put in the formula of weighted average for calculation of the average minimum needed amount of calories per person per year (c_N).

So after calculations the average minimum needed amount of calories per person per year is 782740.1 $(c_N = 782740.1)$.

5.1.2 Total calorie supply per unit of time

The second important variable to be calculated is the total calorie supply per unit of time represented by (a_T). As it was mentioned above, both ways of calculation of this variable described in the Methodology part will be used in the Practical part of the research.

Firstly, the data about food production in tonnes will be recalculated to find the world food production in calories per year. For this the data sets about world food production in 2015 – 2016 and average calorie values by 1 gram will be used.

Now it is possible to recalculate the world food production in calories. The following table represents agricultural production of main food categories in calories for the year 2016.

Tab. 13 World food production 2016 in calories

Product of agriculture	**Amount in kcal**
Wheat	1 666 337 400 000 000
Coarse grains	641 920 000 000 000
Rice	1 438 920 000 000 000
Oilcrops	2 482 176 000 000 000
Meat	457 028 000 000 000
Dairy	481 680 000 000 000
Fisheries	119 520 000 000 000

Source: Analyzing of the data presented by FAO, 2017

So after summarizing the total amount of the main agricultural food items produced in 2015 – 2016 in calories is 7 287 581 400 000 000. For this research this number represents the total calories produced in the unit of time,
$a_T =$ 7 287 581 400 000 000.

These calculations, however, does not include some factors and also some of the items produced by agriculture. That is why one more method of calculation of the a_T is required.

The second possible way to find the total calorie supply per unit of time, as was mentioned above, is to use the data about food supply per capita in calories provided by FAO.

As far as the only accessible data about food supply per capita are for the year 2013 and are given per day these data should be recalculated into the data per year firstly. After these number should be calculated for the year 2016 using the growth rate.

Food supply per capita per day in calories in 2013 was 2 884 (FAO,2017). As the unit of time same as in the previous case one year will be taken. After multiplying by 365 this number is 1 052 660.

This number represents the total average amount of calories per person produced in the world in 2013. So to know the total food supply in calories using the supply per capita the total population number should be taken. The world population in 2013 according to United Nation Population found was 7 162 million (United Nations Population Found, 2016).

After multiplying food supply per capita for 2013 by population number for 2013, the total food supply in year 2013 in calories is 7 539 150 920 000 000.

Now it is possible to modify this value for the year 2016 using the food production growth rate. After multiplying the total food supply in calories for year 2013 by the food production growth rate for three years (2014, 2015, 2016) the value for the year 2016 is 7 906 851 112 428 730 calories.

Now this value has to be enlarged by the amount of agricultural production for non-food usage. It means that now the value 7 906 851 112 428 730 calories presents only 92% of all the agricultural production. Then 100% of this is 8 594 403 383 074 710 calories. This value represents the total food supply for year 2016 while all the agricultural resources are used for the food production so that $a_T = 8\,594\,403\,383\,074\,710$.

This value may be more accurate because more items of food were used for calculation of total food supply in calories. So for future calculations the second value of the variable a_T will be used.

5.1.3 The population growth rate and the food production grows rate

After a_T and c_N are known the growth rates needs to be defined. The population and food production constant grows rates - n and g have to be calculated.

As the first value, n or the population growth rate will be calculated. The table showing the world total population number for last 11 years will be used firstly.

The table "World population in millions 2007 – 2016 gives information about total population numbers during last 11 years. So the growth rate of population for years 2007 - 2016 should be recalculated using these data. For each year the previous year will be taken as the base. The results of the calculations are presented in the following table.

Tab. 14 Population growth rates 2007 - 2016

Year	Population growth rate
2007	1.155 910 279
2008	2.02 240 058
2009	1.18 079 322
2010	1.161 156 178
2011	0.945 185 057
2012	1.119 873 817
2013	1.558 401 044
2014	1.144 931 583
2015	1.449 475 428
2016	1.143 012 655

Source: Recalculated data of United Nations Population Found, 2016

Table 11 represents population growth rate for each year during last 10 years. As far as the population growth rate (n) is supposed to be a constant, an average population growth rate should be calculated.

According to the table 11 the average population growth rate during last 10 years was 1.288113984 which means that average growth of population was about 1.288 % in relationship to the previous year. So the value of the population growth rate is 1.288 ($n = 1.288$).

The last variable, the food production grows rate (g), is already given in a proper form so there is no need to recalculate it. To find it again the data about the increase of food production during last years are needed. The value of the food production grows rate for this research will be taken as 1.6 ($g = 1.6$) (FAO, 2017).

Tab. 15 The values of the variables

The variable	The value
c_N	782 740.1
a_T	8 594 403 383 074 710
n	1.288
g	1.6

To summarize the findings of this subchapter the table above is given. In this table the values which will be used in the formula of the stationary state are presented.

5.2 Calculation of possible stationary state

This subchapter plays crucial role in this research. The main formula for the estimation of the stationary state will be used here to get the equation of stationary state. The values which were calculated or found in the previous subchapter will be put in the formula.

So the equation (5) will be used for the estimation of possible stationary state. t_P is the variable to be estimated which is time when the population needs of food and global food production will meet each other. It is important to remember that if t_P appears to be less than zero, stationary state cannot be possible in future. The equation below represents the formula of stationary state with values of c_N, a_T, n and g.

$$t_P = \frac{\log(782\ 740.1) - \log(8\ 594\ 403\ 383\ 074\ 710)}{1.6 - 1.288} \tag{7}$$

According to this formula $t_P = -74.10042$.

As far as the result is the negative number, it is possible to conclude that stationary state cannot be achieved in the future according to this calculations. This results are true when using the original theorem with its assumptions (Machay, 2012): the population and food production level grow at constant rates which are positive ($n > 0$; $g > 0$) and when all the current values of the variables are used.

It means that this scenario can change if any of the variables are changed and stationary state may be possible in the future if some conditions are changed. Some of these possible scenarios will be reviewed in the next subchapter.

5.3 Possible scenarios guaranteeing the possibility of the stationary state of population

In this subchapter some of the possible scenarios of the possible stationary state to come in the future will be presented. These different scenarios will be based on the changes in technological growth rate changes and the changes in the lands and soils available for the agricultural needs. For all of this scenarios the population growth indicator (population growth rate per unit of time) and food demand per capita per unit of time (minimal recommended calorie input per person per unit of time) will stay same as in the previous subchapter. As a unit of time one year will be used.

For all the scenarios the following assumptions will be the same:

Assumption 1: Suppose the food – more precisely calories – is equally distributed among the world population.

Assumption 2: Assume the population grows at constant rate which is positive ($n>0$).

Assumption 3: All the agricultural land is used for the food production.

Assumption 4: The age structure of the population is stable.

All these assumption and formulas, equations and calculation principles will be used to build scenarios.

5.3.1 Scenario 1: crucial influence of soil erosion and degradation

The first scenario that will be built is based on the great influence of the soil erosion and degradation on the agricultural lands. Soil erosion and degradation play very important role in food production because they influence the area of agricultural land available. Till now this influence every year was compensated by using more and more land for the agricultural needs. But if there was no more land available for the expanding of the agricultural areas this problem could become much more important.

So to find out how crucial this affect can be changed assumptions will be used:

Assumption 1: Suppose the food – more precisely calories – is equally distributed among the world population.

Assumption 2: Assume the population and food production grow at constant rates which are positive ($n > 0$ and $g > 0$).

Assumption 3: All the agricultural land is used for the food production.

Assumption 4: The age structure of the population is stable.

Assumption 5: The productive land area is a constant number.

Assumption 6: Soil erosion is taken as a rate decreasing the productive land area and is a positive number ($s > 0$).

As far as there is a new variable influencing the food supply new formula of calculating the time of the stationary state is needed. New formula with soil erosion rate value (s) has the following form:

$$t_P = \frac{\log c_N - \log a_T}{(g-s)-n} \quad (8)$$

As far as the values of the variables the population growth rate (n), minimal recommended calorie input per person per unit of time (c_N), the total calorie supply per unit of time is represented by (a_T) and technological growth (food production grows) rate (g) are already known the only value to be found is soil erosion rate (s). This value should change the food supply.

The growth rate of the food production or technological growth rate influence the total food supply by producing more using the same amount of area lands. It means that soil degradation and erosion can influence total food supply in an opposite way decreasing the total number of agricultural production.

To calculate the value of the soil degradation rate two main indicators will be taken:

1. Area of land which is lost every year for agricultural use because of the soil degradation and erosion (L_s).
2. Total area of agricultural land (L).

Both these values will be put in the formula below to find the rate of soil degradation and erosion:

$$s = \frac{L_s}{L} \quad (9)$$

The table below shows both this values.

Tab. 16 Per year values of L_s and L

Indicator	Area in 1000 ha
Land with soil degradation and erosion	12 000
Total agricultural land	4 900 105.17

Source: FAO, 2017 and UN, 2016.

After putting this numbers into the formula above the following could be gotten:

$$\frac{12000}{4\,900\,105.17} * 100 = 0.244\,892\,703 \quad (10)$$

So when the rate of soil degradation and erosion is known ($s = 0.2448927030$) all the values can be used in the equation for the firsts year:

$$t_P = \frac{\log(782\,740.1) - \log(8\,594\,403\,383\,074\,710)}{(1.6 - 0.244\,892\,703) - 1.288}$$

$$t_P = -344.512\,93 \quad (11)$$

As far as the number is still negative it is reasonable to create new assumption to see what possible changes can come.

Assumption: Current soil erosion rate will double because of insufficient usage of land resources ($s^* = s * 2$).
The new calculation have to be done with s^* (the rate of soil degradation and erosion which is doubled):

$$s^* = s * 2 \tag{12}$$

After calculating the value of $s^* = 0.489\ 785\ 4060$.

So the new equation looks like this:

$$t_P = \frac{\log(782\ 740.1) - \log(8\ 594\ 403\ 383\ 074\ 710)}{(1.6 - 0.489\ 785\ 406) - 1.288}$$

$$t_P = 130.04066 \tag{13}$$

After assuming increase in soil erosion and degradation without usage of new unused before lands gives the possible time of the stationary state of population to happen. It is 130 years.

So it means that the scenario which includes the limitation in usage of new land resources for the agricultural production explains the possibility of the stationary state to happen in 130 years or 47 464 days.

5.3.2 Scenario 2: no more technological growth

According to previous analysis it is obvious that every year's population growth and caused by this the growing demand for food was supported by the growing food production which was provided by the growth of technology. It means that the technological growth plays very important role in the food supply. In this section the situation of no longer technological growth will be analyzed.

For this reason, the following assumptions will be used:

Assumption 1: Suppose the food – more precisely calories – is equally distributed among the world population.

Assumption 2: Assume the population number grows at constant rate which is positive ($n > 0$).

Assumption 3: All the agricultural land is used for the food production.

Assumption 4: The age structure of the population is stable.

Assumption 5: The technological growth rate is a constant and it is equal to 0 ($g = 0$).

In this case the values of the population growth rate (n), minimal recommended calorie input per person per unit of time (c_N), the total calorie supply per unit of time is represented by (a_T) will be taken as known according to the previous calculations. The value of the technological growth rate will be taken as equal to 0 ($g = 0$).

After putting the numbers into the formula this is the new model and the new value of the time of stationary state of the population:

$$t_P = \frac{\log(782\ 740.1)\ -\ \log(8\ 594\ 403\ 383\ 074\ 710)}{0 - 1.288}$$

$$t_P = 17.949\ 79 \tag{14}$$

So the value of the time of the stationary state of the population to come in this case is 0.302 900 8132 ($t_P = 17.949\ 79$). As far as the number is positive it means that in case of no longer technological growth the stationary state is possible in the future and may come in approximately 17 years and 11 months.

5.3.3 Scenario 3: influence of changes in diets

World diets were changing fast during the last 50 years. These changes put food production under pressure because the production of livestock products is much more expensive, difficult and resource demanding than the production of grains. As far as production of livestock products is more demanding it basically means that the fewer calories can be produced on the same land territory.

For the third scenario the influence of changes in world's diets will be analyzed. According to these changes the new variable - the rate of food calorie production increase caused by an increase in global meat, milk and eggs consumption will be used (b).

The following assumptions will be used in this case:

Assumption 1: Suppose the food – more precisely calories – is equally distributed among the world population.

Assumption 2: Assume the population and food production level grow at constant rates which are positive ($n > 0$; $g > 0$).

Assumption 3: All the agricultural land is used for the food production.

Assumption 4: The age structure of the population is stable.

Assumption 5: The rate of the needed food calorie production increase caused by an increase in global meat, milk and eggs consumption is constant and positive ($b > 0$).

Assumption 6: The productive land area is a constant number.

So the new formula for calculating of the time of stationary state to come has the following form:

$$t_P = \frac{\log c_N - \log a_T}{(g-b)-n} \tag{15}$$

As far as the values of the variables the population growth rate (n), minimal recommended calorie input per person per unit of time (c_N), the total calorie supply per unit of time is represented by (a_T) and technological growth (food production grows) rate (b) are already known the only value to be calculated is the rate of the needed food calorie production increase caused by an increase in global meat, milk and eggs consumption (b).

Livestock contribute 40% of the global value of agricultural output now. It takes from 5 to 10 times more grain or soil to get the equivalent calories from livestock products than from actually eating the feed grain itself (FAO, 2017).

World total production of livestock products is presented in the tables below.

Tab. 17 World production of livestock products

Product group	**Production in million tonnes**		
	2013	**2014**	**2015**
Meat products	311.3	315.3	318.8
Dairy and eggs products	767.5	789	800.7

Source: FAO, 2017

Using the data from the table above the growth rates of livestock production were calculated.

Tab. 18 Growth rates of livestock production

Product group	**Growth rates**	
	2014	**2015**
Meat products	1.0128	1.0111
Dairy and eggs products	1.028	1.0148

Source: FAO, 2017

So after calculating the average numbers of these growth rates for the last two years the growth rate per year for meat products is 1.01195 and the growth rate per year for dairy and eggs products is 1.0214. And for all the livestock products average of this rate is 1.016 675 then.

Now the rate of the needed food calorie production increase caused by an increase in global meat, milk and eggs consumption (b) will be calculated in 3 steps:

1. *Calculating of the growth rate of the total agricultural production needed for providing of the growth of the livestock production.* According to the data of FAO (2017), 40% of the agricultural production is used for animal feed. After calculating the averages of livestock products production growth rates the rate of 1.016 675 was estimated. But this number only shows the production growth rate of 40% of the total agricultural production. It means that it should be recalculated to get the rate which will represent the growth of the total agricultural production needed because of the production of the livestock products. So 40 percent of the total agricultural production grow with a rate of 1.016675. Then for all 100 percent this growth will be represented by the rate of 0.40667 (1.016675*40%).

2. *Calculating of the growth rate of the total calorie production needed for providing of the growth of the livestock production.* So the growth rate of the total agricultural production required by the growth of the production of livestock products is 0.40667. Now it is important to calculate the change in calorie supply which will happen because of higher production of the livestock products. As far as this growth of livestock calorie production will require 5 to 10 calories more as the growth of calorie production of grains the number 7.5 will be taken as average. The required growth rate of the total agricultural production is 0.40667 but for producing every of these additional calories 7.5 times more calories will be used than for production of grains. So this rate has to be multiplied by 7.5 to get the required growth rate of the total agricultural production caused by production of livestock products. After multiplying of 0.40667 by 7.5 the new rate is 3.050025.
3. *The growth rate of the total calorie production needed for providing the growth of the grain production.* It is important to understand that if these calories were used for grain production it would require only 0.40667 rate growth.
4. *Estimating the the rate of the needed food calorie production increase caused by an increase in global meat, milk and eggs consumption.* The rate of 3.050025 which was calculated before has to be decreased by this value (0.40667). So after this decrease the rate of the needed food calorie production increase caused by an increase in global meat, milk and eggs consumption (b) is 2.643355.

The formula with all the values used has the form:

$$t_P = \frac{\log(782\,740.1) - \log(8\,594\,403\,383\,074\,710)}{(1.6 - 2.643\,355) - 1.288}$$

$$t_P = 9.91669 \tag{16}$$

The result is positive that means that changes in diets and the needed food calorie production increase caused by an increase in global meat, milk and eggs consumption can influence the current state of food supply and food demand and provide the conditions for the stationary state of population to happen in the future. The time of the possible future stationary state of population according to these calculations is 9 years and 11 months or 3 620 days.

6 Discussion

The results of the calculations made in this diploma thesis have showed that according to the estimated calorie model the future stationary state of population is not possible in the nowadays state of food supply and food demand. This shows that Malthus population theory was not predicting enough.

The following difficulties were found while estimating the calorie model, processing the calculations and collecting the data:

1. Recommended minimal daily amounts of daily calories input for different age groups. Usually these values are given according to the level of physical activity levels. This values may be not totally correct as far as it was almost impossible to calculate the groups of population according to the level of activities.
2. Data sets for estimation of total food supply per unit of time. Firstly, it was aimed to take the data about the food production in tonnes and recalculate it into calorie values. As far as the information about all the food production groups was not available this number was calculated using the food supply per capita and population numbers.
3. Assumption 3: All the agricultural land is used for the food production. As far as this assumption is crucial for the estimation of the stationary state the data about total food supply per unit of time had to be recalculated to fit this assumption. Unfortunately, there is no data available about the calorie value of the agricultural production for non-food usage. The data were recalculated using the percentage of agricultural production used for production of fuel and material. This could influence the results slightly.
4. The technological production growth rate. As far as the data about the technological growth rate in the food production are not available the data about the food production growth rate were taken. This can only slightly influence the results because the area of the agricultural land stayed almost same during the reviewed time the production growth was mostly provided by the technological growth.

According to the conclusions the future researches in this sphere can be improved by 1) analyzing each country separately because in reality the distribution of food is not same all over the world; 2) more precise analyzes of the data about food production and finding the possibility of calculating the data in tonnes for all the agricultural production groups; 3) finding new ways of calculating the agricultural production of non-food items in calories; 4) enriching the research with scenario of ageing of the population.

7 Recommendations

This diploma thesis, the calorie model estimated in it and the calculations of the possible future stationary state of population let me conclude that following recommendations can be formed:

1. The global food security and the global food problem are not the issues of the food production and food supply. The production of food and the predicted production of food can provide all the total population and the predicted total population with enough amount of calories.
2. The calculations prove that the population growth presented by geometrical progression and food production growth presented by arithmetical progression predicted by Thomas Robert Malthus are not the nowadays threats.
3. While the technological growth succeeded in providing enough food supply for the growing number of population the reasons of hunger and undernourishment should be found in another spheres such as food distribution and food pricing.
4. But even while the future stationary state is not possible according to the used model there are some factors that should be watched and put under control to keep the food supply on the safe level. Firstly, the soils must be used appropriately to prevent future degradation and erosion which decreases the areas which can be used for the agricultural production. The other important aspect of this problem is keeping the investment in the food production and agriculture on the high level. These two points are crucially important for provide the future growth of food supply on the sustainable level.

8 Conclusion

In this diploma thesis the academic literature and publications regarding population problem and global food supply and demand were reviewed. Different approaches to the population problem were presented to show the difference in theoretical opinions. The two main theories of population with opposite opinions - Ester Boserup and Malthus' population theories – were analyzed to understand the two main different approaches to the population growth. This was done in order to have the theoretical base of the research which helps to understand the results better.

As the main tool of the practical part the calorie model was used to estimate the possible time of stationary state of population in the future. The aim of this calculations was to found out if in the existing conditions there is a possibility for the stationary state of population to happen sometime in the future. Basically it means that if the found variable – time of the stationary state to come (t_P) is positive the stationary state situation is possible in the future and if the variable is negative – the stationary state situation is not possible in the future according to the nowadays situation of food supply and food demand.

After estimating the calorie model and calculating the time of possible future stationary state of population the results showed that the variable of the time of possible stationary state of population is negative ($t_P = -74.10042$). This means that according to the buit calorie model in the existing state of food supply and food demand the stationary state of population is not possible in the future.

After that three scenarious were built to show the possible changes in the state of food supply and food demand and its influence on the time of possible stationary state of population. The first scenario included the crucial influence of soil erosion and degradation in case there is no more new land available for agricultural needs. For this scenario the calorie model was changed and the lost of food production because of soil erosion and degradation was taken into the account. So after the calculations the results showed that in this case the time of possible stationary state of population can be positive ($t_P = 130.04066$) and will come in about 130 years. The second scenario was built according to the assumption of no longer technological growth so that the production technological growth was taken as zero. In this case after calculations the time of possible stationary state of the population was again greater than zero and with this assumption the possible stationary state can happen in about 18 years ($t_P = 17.94979$). The last scenario that was built showed the influence of changes in diets. As far as modern changes in diets demand more and more resources for production of livestock products this factor could influence the one part of calorie model – the food supply or the food production. The calculations showed that this factor can play crucial role in changing the possibility of stationary state of population in the future. The time of possible future stationary state of population for the third scenario was the shortest one ($t_P = 9.91669$).

So to conclude if the Malthus' population theory is taken as basis of the all the opinions about the population growth and stationary state of population according to the estimated calorie model the Malthus' population theory seems to be not predicting. The estimated model showed the impossibility of future stationary state of population in the nowadays conditions and showed that there are some crucial factors as soil erosion and degradation, no longer technological growth and changes in diets that can change the possibility of stationary state to happen dramatically.

9 References

Literature sources

AHLBURG, D. Population Growth and Poverty. In Population and Development: Old Debates, New Conclusions, ed. Robert Cassen. New Brunswick, NJ: Transactions Publishers, 1994. 360 p. ISBN 978-3-540-60709-0

ANDERSON, T. You Have to Admit It's Getting Better: From Economic Prosperity to Environmental Quality. Hoover Institution Press Publication, 2013. 300 p. ISBN 08-179-4483-4.

BIRDSALL, N., A. KELLEY a S. SINDING. Population matters: demographic change, economic growth, and poverty in the developing world. New York: Oxford University Press, 2001, 440 p. ISBN 01-992-4407-3.

EHRLICH, R. The population bomb. Ballantine Books, 1971. 201 p. ISBN 1-56849-587-0

DU, S., **MROZ T. A., ZHAI F., POPKIN B. M.** (2004). Rapid income growth adversely affects diet quality in China—particularly for the poor! Social Sci. Med, 59, 1505–1515.

GIMENEZ, M. (1973). Befolkningsproblemet: Marx kontra Malthus" (The Population Issue: Marx vs. Malthus). Journal of the Institute of Development Research. Copenhagen, Denmark. 74-88.

GORDON April A. and Donald. L GORDON.: Understanding Contemporary Africa. United States of America, United Kingdom: Lynne Rienner Publishers, Inc., 2007. 235p. ISBN – 13: 978-1-58826-466-4

GRAHAM, E. (2004). The Past, Present and Future of Population Geography: Reflections on Glenn Trewartha's Address Fifty Years On. POPULATION, SPACE AND PLACE. 10, 289–294. ISSN 1544-8452.

HAYAMI and GODO. Development economics: from the poverty to the wealth of nations. 3rd ed. New York: Oxford University Press, 2005, 430 p. ISBN01-992-7270-0.

HAWKES, C. (2005). The role of foreign direct investment in the nutrition transition. Public Health Nutr. 8, 357–365. DOI:10.1079/PHN2004706

HINDE, Andrew. Demographic Methods. London : Hodder Education, 1998, 305 pgs. ISBN 978 0 340 71892 6

KAUTILYA. The Arthashastra. Penguin Books Limited, 2000. 700 p. ISBN 978-8-1847-5011-9

KEARNEY, J. Food consumption trends and drivers. Philosophical Transactions of the Royal Society B: Biological Sciences. 2010; 365(1554):2793-2807. doi:10.1098/rstb.2010.0149.

KIRK, D. (1996). Demographic Transition Theory. Population Studies, 50, 361-387. DOI: 10.1080/0032472031000149536

KUMAR, A. (2005). The structure and principles of public organization in Kautilya's Arthashastra. The Indian Journal of Political Science, 66(3), 463-488.

LABINI, Paolo Sylos. Underdevelopment: A strategy for reform. Cambridge: Cambridge University Press, 2001, 214 p. ISBN 05-215-8869-3

LALLUKKA, T., LAAKSONEN M., RAHKONEN O., ROOS E., LAHELMA E. (2009). Multiple socio-economic circumstances and healthy food habits. Cent. Eur. J. Public Health 17, 55–63.

LEDBETTER, R. A History of the Malthusian League, 1877-1927. Ohio State University, 1976. 261 p. ISBN 978-0-8142-0257-9

MACFARLANE, Alan. The savage wars of peace: England, Japan and the Malthusian trap. Cambridge, MA: Blackwell Publishers, 1997, 427 p. ISBN 06-311-8117-2

MALTHUS, T.: An Essay on the Principle of Population(1807), New York, NY, USA: Oxford University Press, 2008. 172 p. ISBN 978-0-19-954045-7

MARMOT, M. (2002). The influence of income on health: views of an epidemiologist. Health Aff. *(*Millwood*)* 21, 31–46. DOI:10.1377/HLTHAFF.21.2.31.

MARTIN, S. (2001). Heavy Traffic: International Migration in an Era of Globalization. The Brookings Review, 19(4), 41-44. DOI:10.2307/20081005

MARQUETTE, C. (1997). Turning but not toppling Malthus: Boserupian theory on population and the environment relationships. Working paper no. 16. Bergen (Norway): Chr. Michelsen Institute (CMI), 19 p. ISSN 0804-3639

MENDEZ, M., B. M. POPKIN (2004). Globalization, urbanization and nutritional change in the developing world. J. Agric. Dev. Econ. 2, 220–241

National Academy of Sciences: Rapid population growth: Consequences and policy implications. Baltimore: Published for the National Academy of Sciences by the Johns Hopkins Press, 1971, xii, 696 p. ISBN 08-018-1263-1

POPKIN, B. M. (1999). Urbanization, lifestyle changes and the nutrition transition. World Dev. 27, 1905–1916. DOI:10.1016/S0305-750X(99)00094-7.

POPKIN, B. M. (2006). Technology, transport, globalization and the nutrition transition food policy. Food Policy 31, 554–569. DOI:10.1016/j.foodpol.2006.02.008.

PUTNAM, J., J. E. ALLHOUSE (1999). Food consumption, prices and expenditures, 1970–1997. US Department of Agriculture Statistical Bulletin 965 Washington, DC: US Department of Agriculture.

REARDON, T., J. F. M. SWINNEN (2004). Agrifood sector liberalization and the rise of supermarkets in former state-controlled economies: a comparative overview. Dev. Policy Rev. 22, 515–523. DOI:10.1111/j.1467-7679.2004.00263.x.

REARDON, T., C. P. TIMMER, C. B. BARRET, J. BERDEGUE (2003). The rise of supermarkets in Africa, Asia, and Latin America. Am. J. Agric. Econ. 85, 1140–1146. DOI:10.1111/j.0092-5853.2003.00520.x.

REVELLE, Penelope and Charles. The Environment: Issues and Choices for Society. 2nd edition. USA : PWS Publishers, 1984. 680 pgs. ISBN 0-87150-788-9

SCHOR, J. (1999). The overspent American: why we want what we don't need. New York, NY: Harper Perennial

SEN, Amartya Kumar. Development as freedom. 1st pub. Oxford: Oxford University Press, 1999, 366 p. ISBN 0-19829758-0

SIEGEL, Jacob S. Applied Demography: Applications to Business, Government, Law, and Public Policy. 1st edition. Bingley, United Kingdom: Emerald Group Publishing Limited, 2008, 686 pgs. ISBN 978-0-12-641840-8

SIEGEL, J. S., SWANSON, A. D.: The methods and materials of demography, 2nd ed. Bingley: Emerald, 2009, 819 p. ISBN 978-0-12-641955-9

SMIL, V. (2000). In Feeding the world. A challenge for the twenty-first century. Cambridge, MA: MIT Press

SWAMINATHAN, M. R. BHAVANI (2013). Food production and availability - Essential prerequisites for sustainable food security. The Indian Journal of Medical Research. 138(3): 383-391.

TANG, Z. (1995). Confucianism, Chinese culture, and reproductive behavior. Population and Environment, 16, 269 p. DOI 10.1007/BF02331921.

THIRLWALL, A.P. Growth and Development With Special Reference to Developing Economies. 8th ed. New York: Palgrave Macmillan, 2006, 685 p. ISBN 1-4039-9600-8

THOW, A. M. (2009). Trade liberalization and the nutrition transition: mapping the pathways for public health nutritionists. Public Health Nutr. 12, 2150. DOI:10.1017/S1368980009005680.

THOW, A. M., HAWKES C. (2009). The implications of trade liberalization for diet and health: a case study from Central America. Global Health 28, 5. DOI:10.1186/1744-8603-5-5.

TODARO, M. P. and S.C. SMITH. Economic development. 11th edition. Harlow: Pearson Education Limited, 2011. 801 p. ISBN 978-1-4082-8447-6

VASILESKA, A., G. RECHKOSKA (2012). Global and Regional Food Consumption Patterns and Trends, Procedia - Social and Behavioral Sciences. 363-369. ISSN 1877-0428.

VILLARREAL, M. and **STLOUKAL, L.** (2005). Population, development and food security: An unresolved challenge for the twenty-first century. Genus, 61(3/4), 215-246.

ZHAI, F., H. WANG, S. Du, Y. He, Z. WANG, B. M. POPKIN (2009). Prospective study on nutrition transition in China. Nutr. Rev. 67(Suppl. 1), 56–61.

Electronic Sources

AHITUV, A. (2001). Be Fruitful or Multiply: On the Interplay between Fertility and Economic Development. Journal of Population Economics, 14(1), 51-71. [cit. 2017-02-18]. Available at: http://www.jstor.org/stable/20007749

ALIGICA, P. (2009). Julian Simon and the "Limits to Growth" Neo-Malthusianism [online]. Electronic Journal of Sustainable Development 1, no. 3 (Summer 2009): 49-60. [cit. 2017-02-06]. Available at: https://www.mercatus.org/system/files/JULIAN_AND_THE_LIMITS_TO_GROWTH_NEO-MALTHUSIANISM.pdf

Food and Agriculture Organization of the United Nations. Agriculture and food security [online]. FAO, 2017 [cit. 2017-02-26]. Available at: http://www.fao.org/docrep/x0262e/x0262e05.htm

Food and Agriculture Organization of the United Nations. FAOSTAT: Food Balance Sheets [online]. FAO, 2017 [cit. 2017-04-16]. Available at: http://www.fao.org/faostat/en/#data/FBS

Food and Agriculture Organization of the United Nations. Food Outlook: Biannual Report on Global Food Markets [online]. FAO, 2017 [cit. 2017-03-26]. Available at: http://www.fao.org/3/a-I5703E.pdf

Food and Agriculture Organization of the United Nations. Food Security [online]. FAO, 2017 [cit. 2017-02-26]. Available at: http://www.fao.org/forestry/13128-0e6f36f27e0091055bec28ebe830f46b3.pdf

Food and Agriculture Organization of the United Nations. Human energy requirements [online]. FAO, 2017 [cit. 2017-04-18]. Available at: http://www.fao.org/forestry/13128-0e6f36f27e0091055bec28ebe830f46b3.pdf

Food and Agriculture Organization of the United Nations. Summary of requirements for energy and protein [online]. FAO, 2017 [cit. 2017-03-26]. Available at: http://www.fao.org/3/a-y5686e.pdf

Food and Agriculture Organization of the United Nations. The State of Food Insecurity in the World 2015 [online]. FAO, 2017 [cit. 2017-02-26]. Available at: http://www.fao.org/hunger/en/

MACHAY, M. (2012). The Principle of Population for the 21st Century: The Never Coming Stationary State. MENDELU Working Papers in Business and Economics 18/2012. Mendel University in Brno. Available at: http://vyzc.pef.mendelu.cz/cz/publ/papers

Population Reference Bureau. Human Population: Environment [online]. Population Reference Bureau, 2016 [cit. 2017-02-29]. Available at: http://www.prb.org/Publications/Lesson-Plans/HumanPopulation/Environment.aspx.

RAY, D., N. MUELLER, P. WEST, J. FOLEY (2013) Yield Trends Are Insufficient to Double Global Crop Production by 2050. PLoS ONE 8(6): e66428. https://doi.org/10.1371/journal.pone.0066428

United Nations. Definitions of population indicators [online]. United Nations, 2016 [cit. 2017-01-29]. Available at: http://www.un.org/en/development/desa/population/publications/pdf/policy/WPP2013/Chapters/f_Definitions%20of%20Population%20Indicators.pdf

United Nations. Estimates of population and its percentage distribution by age group and sex, and sex ratio, for the world, major areas and regions [online]. United Nations, 2016 [cit. 2017-03-30]. Available at: https://unstats.un.org/unsd/demographic/products/dyb/dyb2015/Table02.pdf

United Nations. Global Food and Nutrition Scenarios [online]. United Nations, 2016 [cit. 2017-03-10]. Available at: http://www.un.org/en/development/desa/policy/wess/wess_bg_papers/bp_wess2013_millennium_inst.pdf

United Nations. Population Growth Rate [online]. United Nations, 2016 [cit. 2017-01-26]. Available at: http://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/demographics/population_growth_rate.pdf.

United Nations. World Population Ageing 1950-2050: Population Division, DESA [online]. United Nations, 2016 [cit. 2017-01-24]. Available at: http://www.un.org/esa/population/publications/worldageing19502050/pdf/95annexi.pdf.

United Nations Population Found. The State of World Population 2016 [online]. United Nations Population Found, 2016 [cit. 2017-04-14]. Available at: http://www.unfpa.org/sites/default/files/pub-pdf/The_State_of_World_Population_2016_-_English.pdf

United States Census Bureau. International Data Base. World Population by Age and Sex. United States Census Bureau, 2017 [cit. 2017-04-04]. Available at: https://www.census.gov/population/international/data/idb/worldpop.php

United States Department of Agriculture. Estimated Calorie Needs per Day by Age, Gender, and Physical Activity Level. United States Department of Agriculture, 2017 [cit. 2017-03-24]. Available at: https://www.cnpp.usda.gov/sites/default/files/usda_food_patterns/EstimatedCalorieNeedsPerDayTable.pdf

World Health Organization. Glossary of Humanitarian terms [online]. World Health Organization, 2017 [cit. 2017-01-26]. Available at: http://www.who.int/hac/about/definitions/en/.

World Health Organization. Natural population growth rate [online]. World Health Organization, 2017 [cit. 2017-01-23]. Available at: http://www.searo.who.int/entity/health_situation_trends/data/chi/natural-population-growth-rate/en/.

World Resources Institute. The Global Food Challenge Explained in 18 Graphics by Janet Ranganathan [online]. World Resources Institute, 2013 [cit. 2017-01-26]. Available at: http://www.wri.org/blog/2013/12/global-food-challenge-explained-18-graphics.

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