

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**FEASIBILITY AND SUSTAINABILITY ANALYSIS OF
BIOETHANOL PRODUCTION FROM DIFFERENT STARCHY
FOOD WASTES IN TURKEY FOR GASOLINE BLENDING BASED
ON DIFFERENT SCENARIOS AND MODELS TILL 2030**

BURCU TRKMEN
A THESIS SUBMITTED FOR THE DEGREE OF
MASTER OF SCIENCE
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T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

**FARKLI SENARYO VE MODELLERLE
2030 YILINA KADAR TÜRKİYE’DE BENZİN
KATKISI OLARAK KULLANILMAK İÇİN
ÇEŞİTLİ NIŞASTA BAZLI GIDA
ATIKLARINDAN BİYOETANOL
ÜRETİMİNİN FİZİBİLİTE VE
SÜRDÜRÜLEBİLİRLİK ANALİZİ**

BURCU TÜRKMEN
YÜKSEK LİSANS TEZİ
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DANIŞMANI
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GEBZE
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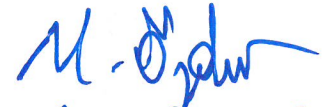
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...../...../..... tarih ve/..... sayılı kararı.

SUMMARY

First generation (1st generation) bioethanol production can be sustainable if food wastes are used as feedstock. As a novelty, in this thesis study, Turkey's wheat, maize, rice and potato production, consumption, associated losses and bioethanol yield from these streams are forecasted between 2017 and 2030. It is estimated that Turkey's wheat, maize, rice and potato (i) production, (ii) consumption, (iii) production losses, (iv) consumption losses, (v) bioethanol yield from production losses, and (vi) bioethanol yield from consumption losses in 2030 will be (i) 25.0, 6.2, 0.6 and 5.5 million tonnes; (ii) 19.3, 1.5, 0.8 and 4.7 million tonnes; (iii) 1.375, 0.184, 0.006 and 0.094 million tonnes, (iv) 0.710, 0.182, 0.020 and 0.160 million tonnes, (v) up to 0.511, 0.073, 0.003, and 0.009 billion litres of bioethanol, and (vi) up to 0.264, 0.072, 0.009, and 0.015 billion litres of bioethanol, respectively. Also, it is estimated that if collected and processed properly, in 2023, up to 0.555 and 0.335 billion litres of bioethanol can be collectively generated from Turkey's wheat, maize, rice and potato production and consumption losses, respectively; and these amounts will be more than enough to supply Turkey's potential bioethanol demand (as a substitute to gasoline) of 2023. Finally, it is believed that the methodology given in this thesis study can be used by policy analysts and researchers around the globe to prepare national and/or local bioethanol generation scenarios from wasted crops and cereals.

Key Words: bioethanol, cereals, food waste, modelling, Turkey.

ÖZET

Gıda atıkları hammadde olarak kullanıldığında birinci nesil biyoetanol üretimi sürüdürülebilir hale gelebilir. Bu tez çalışmasında 2017- 2030 tarihleri arasında Türkiye'nin buğday, mısır, pirinç ve patates üretimi, tüketimi, bunlara bağlı olarak ortaya çıkan üretim ve tüketim kayıpları ve biyoetanol verimi öngörülerek yeni bir soluk kazandırılmıştır. Türkiye'nin 2030 yılında buğday, mısır, pirinç, patates (i) üretim, (ii) tüketim, (iii) üretim kayıpları, (iv) tüketim kayıpları, (v) üretim kayıplarından elde edilecek biyoetanol verimi ve (vi) tüketim kayıplarından elde edilecek biyoetanol verimleri sırasıyla (i) 25.0, 6.2, 0.6, 5.5 milyon ton, (ii) 19.3, 1.5, 0.8, 4.7 milyon ton, (iii) 1.375, 0.184, 0.006, 0.094 milyon ton, (iv) 0.710, 0.182, 0.020, 0.160 milyon ton, (v) 0.511, 0.073, 0.003, 0.009 milyar litre ve (vi) 0.264, 0.072, 0.009, 0.015 milyar litre olacağı tahmin edilmektedir. Ayrıca, uygun şekilde toplanır ve işlenirse, 2023 yılında, Türkiye'nin buğday, mısır, pirinç ve patates üretim ve tüketim kayıplarından elde edilen 0.555 ve 0.335 milyar litre biyoetanolün, aynı tarihte benzene alternative olarak kullanılabilecek potansiyel biyoetanol talebini fazlasıyla sağlayacaktır. Son olarak bu tez çalışmasında verilen metodolojinin atık ürün ve tahıllardan ulusal ve /veya yerel politikalar hazırlamada dünya çapındaki araştırmacılar ve politika hazırlama uzmanları tarafından kullanılabileceğine inanılmaktadır.

Anahtar Kelimeler: biyoetanol, gıda atığı, modelleme, tahıl, Türkiye.

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LIST of ABBREVIATIONS and ACRONYMS

<u>Abbreviations</u>	<u>Explanations</u>
<u>and Acronyms</u>	
ε_t	: "Random" error term
%	: Percentile
A	: Availability factor of the cereal or crop production and consumption losses, %
$B_{yfcI}(t)$	: Bioethanol yield from cereal or crop production loss in year t in tonnes
$B_{yfpl}(t)$	: Bioethanol yield from cereal or crop production loss in year t in litres
B_{yoc}	: Bioethanol yield from cereal or crop in litres per tonne
$C_c(t)$	: Cereal or crop consumption in year t in tonnes
$C_{cl}(t)$	: Cereal or crop consumption loss in year t in tonnes
C_{cpc}	: Average cereal or crop consumption per capita in kg
$C_p(t)$	: Cereal or crop production in year t in tonnes
$C_{pl}(t)$	: Cereal or crop production loss in year t in tonnes
C_{ppc}	: Average cereal or crop production per capita in kg
F_{clf}	: Average cereal or crop consumption loss factor
F_{plf}	: Average cereal or crop production loss factor
kg	: Kilograms
ktoe	: Kilotonnes
P(t)	: Population
t	: Year
BAU	: Business as Usual
EU	: European Union
FAO	: Food and Agriculture Organization
FSC	: Food Supply Chain
GDP	: Gross Domestic Product
MENA	: Middle East and North Africa
N/A	: Not applicable or not available
OECD	: Organisation for Economic Co-operation and Development

R&D	:	Research and Development
TL or TRY	:	Turkish Lira
TPES	:	Total Primary Energy Supply
TurkStat	:	Turkish Statistical Institute

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1. INTRODUCTION

Turkey has a unique geographical location between Asia and Europe. The country has very fertile lands and a climate suitable for agriculture. Historically, Turkey has been considered as a crop granary, which is direct translation of the Turkish words “tahıl ambarı”.

Turkey is undoubtedly one of the key countries in the energy geopolitics of Eurasia, since it is strategically located at the meeting point of Europe and Asia. The country also located in close vicinity of the Middle East and North Africa (MENA) region, where majority of the world’s natural gas and petroleum reserves are found [Avcioğlu et al., 2019]. This unique geographical position enables Turkey to present itself as an energy bridge (corridor) and hub (center) of the region [Avcioğlu et al., 2019].

Turkey’s economic welfare, population, gross domestic product (GDP), and energy demand has been increasing since the beginning of the 21st century. The GDP in current United States dollars (US\$) rise from 311.8 billion US\$ in 2003 to 851.5 billion US\$ in 2017 [Web 1, 2019]. In the literature there are various studies that show different correlations between energy consumption and GDP change [Melikoglu, 2016].

Global population increased significantly in the last couple of decades and concurrently global energy consumption skyrocketed. Today, most of the global energy demand is supplied from fossil fuels such as coal, petroleum (oil), and natural gas [Silva et al., 2018]. These fossil fuels are limited resources and their consumption for power generation releases huge amounts of greenhouse gases (GHGs) into the atmosphere. Global warming due to fossil fuel consumption is a major environmental problem. Developed nations of the world aim to reduce fossil fuel consumption in the following decades in order to decelerate and eventually stop global warming. However, this is not an easy task to achieve. This transition can be succeeded by increasing renewable energy consumption and decreasing fossil fuel consumption.

Renewable energy sources provide economic benefits alongside with environmental gains when compared to fossil fuels. Many nations around the world want to utilize environmentally friendly and sustainable energy sources/renewables

in their energy mix. As a result, private sector and government energy investments are focusing into renewable dominated energy mixes [Azhar et al., 2017]. Around the world, energy consumption has been growing alongside with population and industrial development [Zhu et al., 2005], [Melikoglu and Albostan, 2011]. It is envisaged that per capita energy consumption of developed countries will first rise to a maxima, stagnate for a period then decrease. The increase will be related to increasing energy demand and the decrease after stagnation will be related to the increase in energy efficiency.

Today, most of our global energy is produced from limited resources (fossil fuels). As a result, there is a global aim to increase efficiency in consumption. Turkey is a developing country with growing population [Web 2, 2019]. It is expected that Turkey's per capita energy consumption will increase in the following years [Web 3, 2019]. However, Turkey does not have indigenous energy sources. This means that increasing per capita energy consumption alongside with population will increase Turkey's energy demand. This demand will be supplied from imported fossil fuels unless the share of renewables in the country's energy mix is significantly increased. As a result, this is an important topic in terms of energy systems design, operation and security.

Fossil fuels will dominate the global energy market in the years to come and a direct replacement with renewable energy sources does not seem possible in the short and mid-term. However, this is no excuse and adoption of renewable energy sources must be accelerated both at national and global levels. Yet, some of the industrial applications will require combustion based energy generation (i.e. combined heat and power or direct combustion). For example, for metal and chemical industries heat is a required for manufacturing. Producing heat from electricity, which is the case for renewable energy based electricity generation, will decrease the overall efficiency. Renewable energy sources can be used as standalone and also in hybrid systems, where they are utilized alongside with fossil fuels. By this way, fossil fuel consumption is gradually reduced. In the future, certain industries will have hybrid fossil/renewable energy systems. Co-combustion of coal with biomass to produce heat and energy is an example of fossil/renewable hybrid system design. There are also many other examples. This thesis study will focus on biofuels.

Biofuels and waste provides a significant portion of our total global energy consumption. In 2016, it is estimated that nearly 10.0% of our global total primary

energy supply (TPES) was from biofuels and waste [IEA, 2016]. In that concept, global TPES for 2016 is given in Table 1.1 below.

Table 1.1: Total Primary Energy Supply (TPES) of the world by source in 2016.

Fuel Type	TPES (ktoe)
Coal	3,730,886
Natural gas	3,034,954
Nuclear	679,649
Hydro	349,223
Geothermal, solar, etc.	225,627
Biofuels and waste	1,349,289
Primary and secondary oil	4,390,197

From global to local, in Turkey, price of gasoline reached to record levels and exceeded 7.00 TL in 2018 [Web 4, 2018]. Turkey imports most of the petroleum (crude oil) it consumes [Melikoglu, 2013]. As a result, price of gasoline is affected from the price of crude oil, which is purchased in US\$, and the Turkish Lira's (TL or TRY) performance against the US\$. Dependence on foreign petroleum for gasoline (or any other petroleum based fuel) is a serious energy security problem and a major economic liability for Turkey [Melikoglu, 2013].

There are two solutions to this problem. First one is to reduce fuel consumption and the other one is to switch (use) alternative fuels. The first solution is not feasible in the short and mid-term because gasoline has a key role in Turkey's road transportation [Melikoglu, 2014]. Turkey, is an associate European Union (EU) member; therefore, medium-long-term plans must be made soon because EU members as it plans to ban the sale of gasoline (and diesel) motor vehicles in many European countries by 2040-2050 [Web 5, 2018], [Web 6,2018]. Along this road, the other solution is finding a domestic alternative and gradually reducing gasoline consumption. Providentially, such an alternative fuel exists in the form of bioethanol. Bioethanol (ethanol, ethyl alcohol, grain alcohol with the chemical formula C_2H_5OH) is an eco-friendly and renewable alternative fuel for gasoline (spark-ignition) engines [Mohapatra et al., 2019], [Patni et al., 2013], [Roy and Dutta, 2019].

Bioethanol production requires glucose as the primary raw material. Glucose is fermented to produce ethanol. Therefore, raw materials rich in macromolecules (sucrose, starch, etc.), which can be converted into glucose are used for bioethanol

production [Guo et al., 2015]. Raw materials that are used in bioethanol production can be classified under three main groups: (i) Raw materials containing sucrose (sugar beet, sweet sorghum, sugar cane etc.), (ii) raw materials containing starch (wheat, corn, rice, barley, etc.), (iii) lignocellulosic raw materials (hay, wood, grass, etc.) [Gawande, Patil, 2018], [Chen et al., 2018], [Katsimpouras et al., 2018]. Bioethanol production technology for groups (i) and (ii) are now well established. However, for the third group, industrial scale bioethanol production has yet not been feasible and the process is not been optimized. As a result, bioethanol sold in the market today is commonly known as “first generation” (1st generation) bioethanol [Mohapatra et al., 2019], [Chen et al., 2018], [Liu and Lien, 2016].

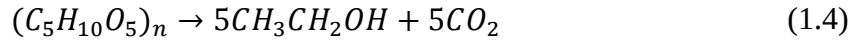
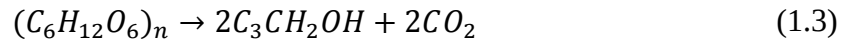
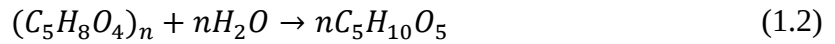
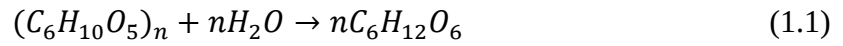
It is expected that second (2nd) generation bioethanol will be sold in the energy market in the second quarter of the 21st century. The production of bioethanol from lignocellulosic sources will be much more economical than 1st generation when the bio-production process is perfected [Melikoglu and Albostan, 2011]. This is because lignocellulosic raw materials are both much greater in quantity and significantly cheaper than cereals [Melikoglu and Albostan, 2011]. Therefore, research and development (R&D) studies on second generation bioethanol production must be fostered by local governments and private sector.

Today, in the United States maize (corn) [Hettinga et al., 2009], Brazil sugarcane and sugar beet [Dias et al., 2009] and Europe wheat are the main raw materials used in the production of bioethanol [Koutinas et al., 2007], [Wang et al., 2009]. Almost all bioethanol sold in the global market is grain/crop originated. In other words, 1st generation bioethanol is food originated. This is a very important global problem and in this thesis study this will be investigated in detail.

Bioethanol is one of the most important renewable fuels contributing to the reduction of negative environmental impacts of petroleum based fuels [Cardona and Sanchez, 2007]. Biomass is currently the only renewable feedstock that is used to produce liquid fuels. Prasad et al., grouped fermentable raw materials as directly fermentable sugar based raw materials, starchy, lignocellulosic materials and urban/industrial wastes [Prasad et al., 2007]. Lignocellulosic materials are the most costly then comes the starch raw materials (crops/cereals food grade). The cheapest is of course and urban/industrial wastes because as raw material they have no cost. However, for all the three groups above collection, transportation, storage,

pretreatment, and bioprocessing have different costs, which must be analyzed case by case.

Glucose is converted to bioethanol and carbon dioxide (CO₂) by fermentation under anaerobic conditions. *Saccharomyces cerevisiae* (*S. cerevisiae*) also known as bakers' yeast, since it is commonly used in the baking industry to ferment glucose to ethanol. Other microorganisms can be used for fermentation but this is not the concern of this thesis study. Details of bioethanol production from different raw materials are explained in Equations (1.1) - (1.4) [Guo et al., 2015]. Bioethanol is ethanol produced from biomass through fermentation, in which the following biochemical reactions are involved;



In Equations (1.1) - (1.4), (C₆H₁₀O₅)_n is a macromolecule formula which stands for starch, cellulose, sugar; C₆H₁₂O₆ is glucose, fructose; (C₅H₈O₄)_n is a macromolecule formula which stands for hemicellulose; C₅H₁₀O₅ is xylose, mannose, arabinose; and finally CH₃CH₂OH is bioethanol.

Excessive consumption of food grade raw materials for 1st generation bioethanol production causes food (fodder) problems and rise/fluctuate prices for commercial bioethanol enterprises [Mohapatra et al.,2019] , [Chen et al.,2018] ,[Katsimpouras,2018]. When food grade raw materials are used to produce bioethanol the problem shifts from engineering to ethical. As a solution, it can be suggested that bioethanol can be produced from imported crops and cereals. However, this would be the same as importing crude oil to produce gasoline (not economic and not environmental).Therefore, sustainability of bioethanol generation in Turkey and anywhere else must be analyzed in detail.

As can be understood from the above discussion, sustainability of bioethanol generation is a major problem whether it is first or second generation. Therefore,

innovative and sustainable solutions must be found during the commercial transition between these two generations. One innovative solution is producing bioethanol from food wastes [Melikoglu,2008].This innovative solution deals with sustainable bioethanol production from global food waste problem. These global food wastes can be all food wastes wasted in consumption starting from production. Examples of food waste are crop wastes, fruit & vegetable peels, catering wastes, waste bread and etc. [Melikoglu and Webb, 2013], [Melikoglu et al., 2013a], [Han et al., 2015], [Melikoglu et al., 2013b], [Melikoglu et al., 2015]. As it can be guessed, the topic of food waste reutilization for bioethanol generation is too broad. Therefore, in this thesis study, focus will be given on bioethanol production from four specific crop/cereal wastes: wheat, maize (corn), rice and potato. In addition, the analysis will be carried out for Turkey. Innovation in such research now lies with crop production/consumption and production losses/consumption losses forecasting rather than direct calculation of yields from current or past production/consumption data. As a result, in this thesis study, Turkey's wheat, maize, rice and potato production, consumption and associated losses will be forecasted between 2017 and 2030 and related bioethanol yields will be estimated.

This thesis is structured as follows: In section 2, results from a detailed literature review about bioethanol yield from different crops and cereals, and previous studies on crop and cereal based bioethanol generation in Turkey are given. Then, in section 3, data and methodology about wheat, maize, rice and potato production, consumption and associated losses in Turkey, and methodology for forecasting Turkey's wheat, maize, rice and potato production, consumption and associated losses between 2017 and 2030 are given. In section 4, forecasting results about Turkey's wheat, maize, rice and potato production, consumption and associated losses in Turkey between 2017 and 2030, and forecasting results about Turkey's potential bioethanol yield from wheat, maize, rice and potato production and consumption losses are given alongside with the related discussion. Finally, conclusions driven from this study are given in the last section of this thesis.

2. LITERATURE REVIEW

2.1. Bioethanol Yield from Different Crops and Cereals

Biofuels can be produced from vegetable oils, sugar beets, cereals, organic wastes, and other types of biomass. Biological raw materials containing significant amounts of sugar - or materials that can be converted to sugar such as starch or cellulose can be utilized to produce bioethanol [Balat et al.,2008].Today, almost all bioethanol sold in the market is from foods (predominantly cereals) [Melikoglu and Albostan, 2011]. The availability of feedstock for bioethanol production can vary considerably from season to season and depend on geographic locations. In order to estimate bioethanol generation from different crops, first, data about bioethanol yield per crop/cereal must be found. Different breeds of the same crop or cereal can yield different amounts of bioethanol. Therefore, it would be beneficial to prepare an average yield table.

After a detailed scrutiny, bioethanol yields from maize, potato, rice and wheat in litres per tonne of crop/cereal are found from the literature and reported in Table 2.1[Patni et al., 2013], [Balat et al., 2008], [Jansson et al., 2009], [Vries et al.,2010], [Ho et al., 2014], [Zabed et al., 2017], [Tasić et al.,2009]. As can be seen from Table 2.1, on average 395, 91, 440 and 372 litres of bioethanol can be produced from a tonne of maize, potato, rice and wheat, respectively. Consequently, these average values are used in the forecasting part of this thesis study.

Table 2.1: Bioethanol yields from maize, potato, rice, and wheat (litres/tonne).

Reference	Bioethanol yield from different crops (litre/tonne)				
	Maize(corn)	Potato	Rice	Wheat	Notes
Balat et al.,2008	360	110	430	340	
Jansson et al.,2009	410	N/A	450	390	
De Vries et al., 2010	386	N/A	N/A	357	
Ho et al.,2014	384	N/A	N/A	333-362 (average: 348)	^{1, 2}
Patni et al., 2013	410	N/A	N/A	390	

Table 2.1: (continued).

Zabed et al., 2017	370-470 (average: 420)	80-100 (average: 90)	N/A	376-435 (average: 406)	²
Tasić et al., 2009		>74			³
Average	395	91	440	372	
Notes: ¹ Calculated from crop yield (tonne/ha) and bioethanol yield (litre/ha) given in the reference publication. ² In different publications where there are ranges of values, in the overall estimation average values of these ranges are used. ³ In the reference publication it is stated that more than 74 litres per tonne. In the calculations it is assumed as 74 litre/tonne.					

2.2. Previous Studies on Crop and Cereal Based Bioethanol Generation in Turkey

Other studies focused on bioethanol capacity and provided a general review about the subject. In 2012, Acaroğlu and Aydoğan reported that Turkey's bioethanol installed capacity was 180 million litres [Acaroğlu and Aydoğan, 2012]. There are also other studies about bioethanol production and potential estimation [Erdal et al., 2009], [Isci, 2012]. A more novel approach is to estimate the amount of bioethanol that can be generated from unused land. At first, this can be seen as possible solution; however, when edible crop or cereal is produced on unused land then its utilisation for bioethanol generation again falls into the cycle of food vs. fuel debate. Instead edible crops generated from unused land can be used for feed, fodder or other sustainable agricultural processes. Yet, in 2011, Melikoglu and Albostan estimated that by growing potato, sugar beet, and wheat (each 100%) on the unused land available for agriculture 5.8, 8.7 and 13.7 billion litres of bioethanol can be produced in Turkey; and they concluded that this amount of bioethanol will be more than enough to supply Turkey's gasoline demand [Melikoglu and Albostan, 2011].

As stated in section 1, the most sustainable way to produce 1st generation bioethanol is to use crop or cereal wastes. After a detailed literature review, it is found that there is no study about forecasting Turkey's bioethanol generation potentials from wheat, maize, rice and potato production and consumption losses. Therefore, novel to this thesis study these will be estimated till 2030 using different

crop production, consumption, and associated loss estimation models. Details of this modelling study will be explained in the section 3.

3. DATA and METHODOLOGY

3.1. Data about Wheat, Maize, Rice and Potato Production, Consumption and Associated Losses in Turkey

In order to estimate bioethanol production potentials from wasted cereals and crops, first, the appropriate production and consumption data must be found from the literature. Maize, potato, rice and wheat are the top four crops/cereals cultivated for human consumption [Zhang et al., 2017], [Durand-Morat et al., 2018], [Dong et al., 2018], [Serna-Saldivar et al., 2016]. These crops are foodstuffs that are essential for human consumption, as well as bioethanol production capacities. However, the use of all of these as a fuel source causes social and economic problems. These crops and cereals are also extensively used in the global bioethanol industry [Wang et al., 2007], [Koga et al., 2013], [Lu et al., 2012], [Eckert et al., 2018]. Therefore, any significant loss or wastes in these feedstock streams become major economic and ethical problems. From global to local, Turkey's wheat, maize, rice and potato production, production losses, consumption and consumption losses between 2007 and 2016 are found the Turkish Statistical Institute (TurkStat) and shown in Figure 3.1 [TurkStat, 2018a].

Here, it must be emphasised that the consumption values given in Figure 3.1 are for humans and only as food. In addition, it is assumed that the loss data given in the source publication [TurkStat, 2018a] is from human consumption. The starting point is selected as 2007, because after this year annual nationwide address based population data has become available in Turkey. In addition, using the data provided by TurkStat, ratios of production losses to production and consumption losses to consumption are calculated and shown in Figure 3.1.

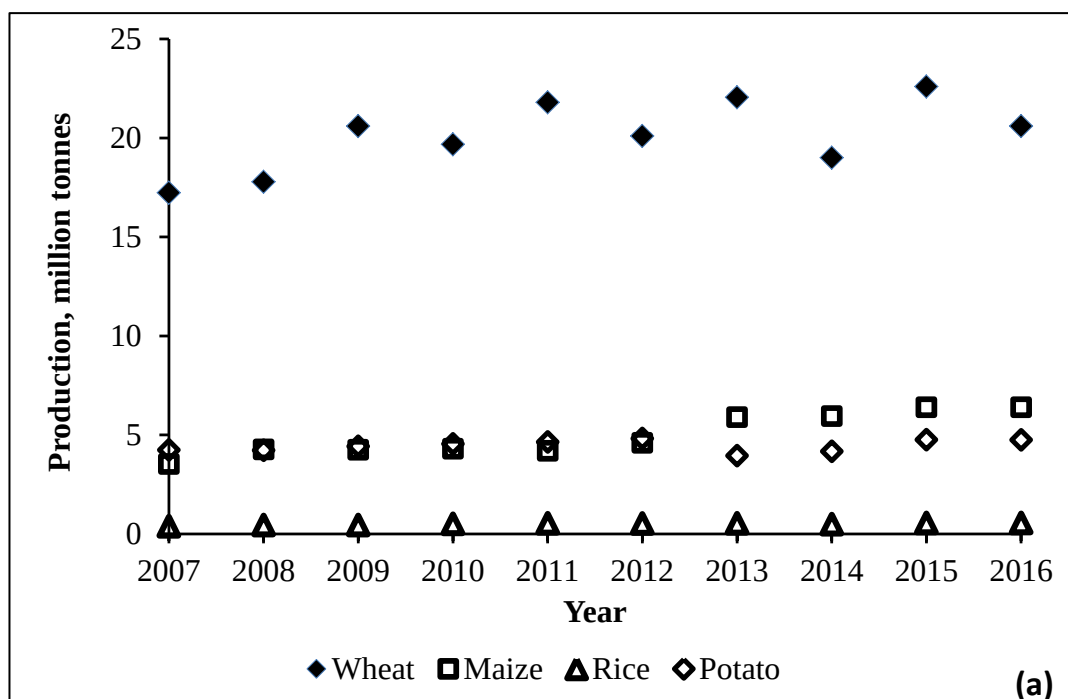


Figure 3.1(a): Wheat, maize, rice and potato production in Turkey, million tonnes.

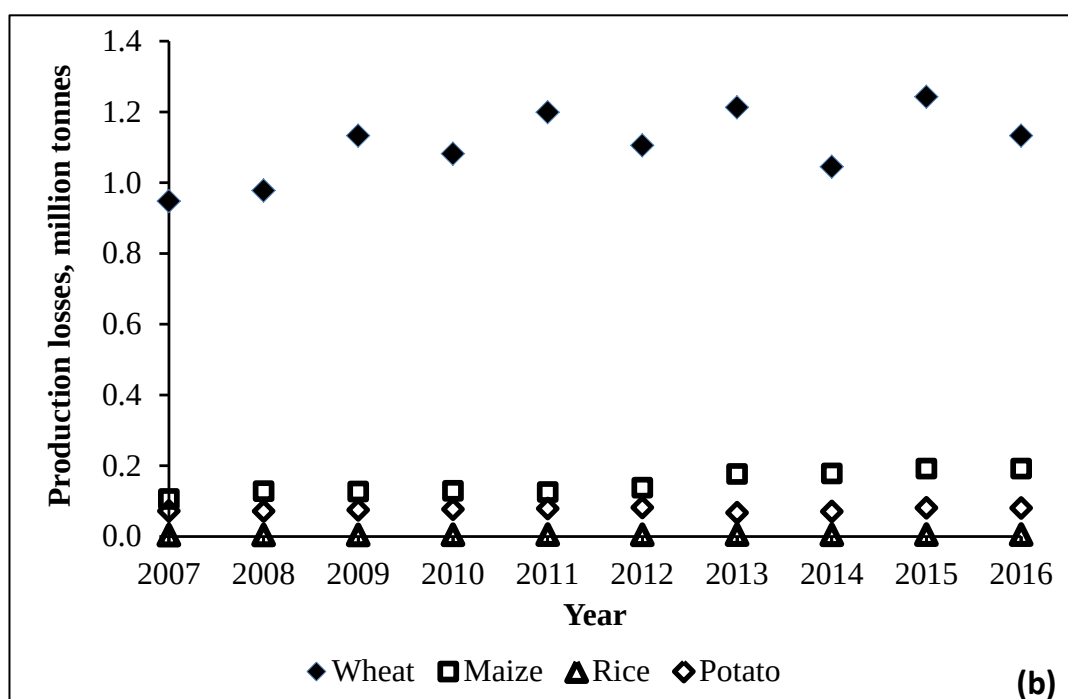


Figure 3.1(b): Wheat, maize, rice and potato production losses in Turkey, million tonnes.



Figure3.1(c): Wheat, maize, rice and potato production losses/production in Turkey, %.



Figure 3.1(d): Wheat, maize, rice and potato consumption in Turkey, million tonnes.

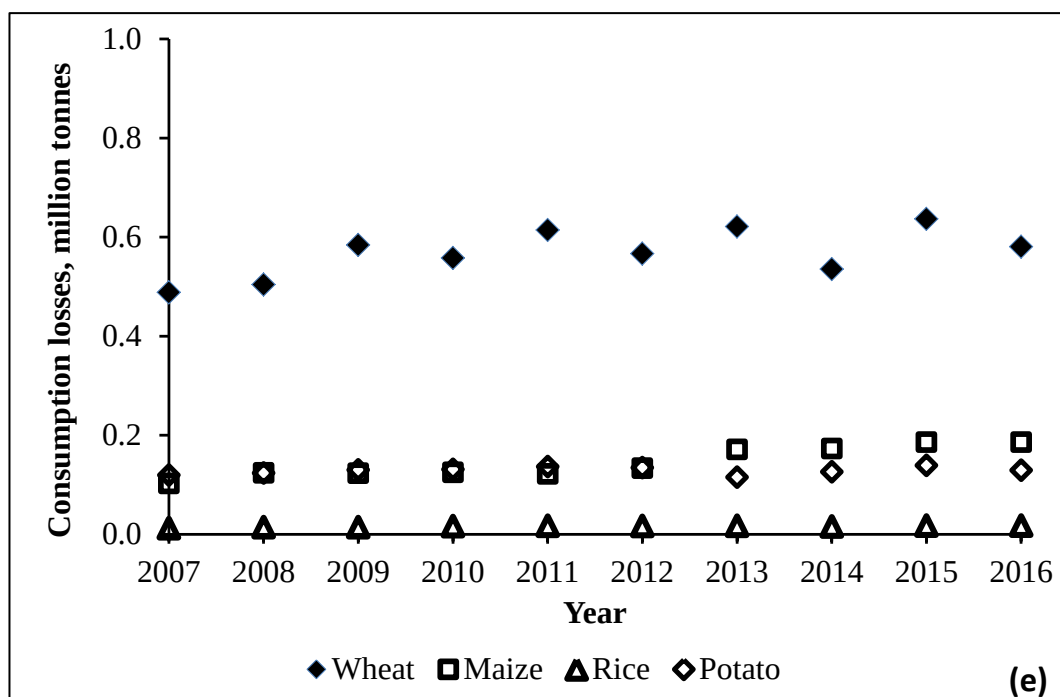


Figure 3.1(e): Wheat, maize, rice and potato consumption losses in Turkey, million tonnes.



Figure 3.1(f): Wheat, maize, rice and potato consumption losses/consumption, %.

As can be seen from Figure 3.1, wheat production is the highest in terms of amount out of the selected cereals and crops. This is followed by maize, potato and rice production. In terms of consumption, wheat is followed by potato, maize and rice. Since the production and consumption of these four cereals and crops are in multiple million tonnes range; concurrently, associated losses is expected to be in multiple thousand tonnes range. As can be seen from Figure 3.1, this estimate for associated losses is true. Therefore, if recovered and processed properly then significant amounts of bioethanol can be generated from these waste/loss streams. Yet, first, Turkey's wheat, maize, rice and potato production and consumption must be accurately forecasted till 2030. When this data is available then associated losses from those streams will be estimated. Finally, using this data and average yield values given in Table 2.1, Turkey's potential bioethanol generation from these waste streams will be estimated. The methodology to do all of this is explained in the following subsections.

3.2. Methodology for Forecasting Turkey's Wheat, Maize, Rice and Potato Production, Consumption and Associated Losses between 2017 and 2030

Turkey's wheat, maize, rice and potato production, consumption and associated losses between 2017 and 2030 are estimated based on the following methodology. First, Turkey's wheat, maize, rice and potato production and consumption per capita values between 2007 and 2016 are found from TurkStat [TurkStat, 2018a]. Then, Equations (3.1) & (3.2) are used to forecast Turkey's wheat, maize, rice and potato production and consumption between 2017 and 2030.

$$C_p(t) = C_{ppc} \times P(t) + \varepsilon_t \quad (3.1)$$

$$C_c(t) = C_{cpc} \times P(t) + \varepsilon_t \quad (3.2)$$

In Equations (3.1) and (3.2), t is year, which is ≥ 2017 , $C_p(t)$ is cereal or crop production in year t in tonnes, $C_c(t)$ is cereal or crop consumption in year t in tonnes, C_{ppc} is average cereal or crop production per capita in kg, C_{cpc} is average cereal or crop consumption per capita in kg, $P(t)$ is population, people, in year t , and ε_t is a

"random" error term. It is assumed that average per capita production and consumption values between 2007 and 2016 can be used for estimating the timespan between 2017 and 2030. The soundness of this decision is assessed in the next paragraph. Consequently, Turkey's C_{ppc} and C_{cpc} values for each type of cereal or crop between 2017 and 2030 are given in Table 3.1 [TurkStat, 2018], [OECD-FAO, 2018]. In addition, Turkey's population data and forecasts between 2017 and 2030 are attained from TurkStat are given in Table 3.2 [TurkStat, 2018b], [TurkStat, 2018c].

Table 3.1: Average values for Turkey's per capita wheat, maize, rice and potato production and consumption values.

Cereal or tuber	Average per capita production values for 2017 and 2030 ^a in kg, current study, C_{ppc} values calculated from [TurkStat, 2018a]	Average per capita consumption values for 2017 and 2030 ^a in kg, current study, C_{cpc} values calculated from [TurkStat, 2018a]	OECD-FAO estimate for per capita production in 2027 [OECD-FAO, 2018]	OECD-FAO estimate for per capita consumption in 2027 [OECD-FAO, 2018]	% difference with the per capita consumption estimate found in the current study and OECD-FAO values
Maize	65.9	16.3	N/A	15.7	3.8% greater than the OECD-FAO estimate (match 96.2%)
Potato	59.3	50.5	N/A	N/A	N/A
Rice	6.7	8.7	N/A	9.2	5.4% smaller than the OECD-FAO estimate (match 94.8%)

Table 3.1: (continued).

Wheat	267.8	206.9	N/A	212.2	2.5% smaller than the OECD- FAO estimate (match 97.5%)
^a These per capita values are average of per capita production and consumption values between 2007 and 2016, which are calculated from [TurkStat, 2018a]					

Table 3.2: Turkey's population data and forecast between 2017 and 2030.

Year	Population, million people
2017	80.8
2018	81.9
2019	82.9
2020	83.9
2021	84.9
2022	85.9
2023	86.9
2024	87.9
2025	88.8
2026	89.8
2027	90.7
2028	91.6
2029	92.5
2030	93.3

As can be seen from Table 3.1, average per capita wheat, maize and rice consumption values of Turkey estimated in this thesis study for the timespan between 2017 and 2030 matched 94% or higher with the Organisation for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization (FAO) of the United Nations (UN) OECD-FAO Agricultural Outlook 2018-2027 per capita consumption estimate for 2027 [OECD-FAO, 2018]. As a clarification, the latest forecast in the OECD-FAO Agricultural Outlook is for 2027. Thus no forecast for 2030 is yet available from this source for comparison. In addition, average per capita production values for wheat, maize, rice and potato are not available in the

OECD-FAO Agricultural Outlook 2018-2027. As a result, based on 94% of higher match with the OECD-FAO data it is believed that average per capita production and consumption values given in Table 3.1 can be used in the forecasting studies. The forecasting results will be given in section 4.

When production and consumption forecasts are available then associated losses must be estimated. As a result, the following methodology and Equations (3.3) &(3.4) are used to forecast Turkey's wheat, maize, rice and potato production - consumption associated losses between 2017 and 2030.

$$C_{pl}(t) = C_p(t) \times F_{plf} + \varepsilon_t \quad (3.3)$$

$$C_{cl}(t) = C_c(t) \times F_{clf} + \varepsilon_t \quad (3.4)$$

In Equations (3.3) and (3.4), t is year, which is ≥ 2017 , $C_{pl}(t)$ is cereal or crop production loss in year t in tonnes, $C_{cl}(t)$ is cereal or crop consumption loss in year t in tonnes, $C_p(t)$ and $C_c(t)$ are cereal or crop production and consumption in year t in tonnes given in Equations (3.1) and (3.2), F_{plf} is average cereal or crop production loss factor, F_{clf} is average cereal or crop consumption loss factor, and ε_t is a "random" error term. It is assumed that average F_{plf} and F_{clf} values between 2007 and 2016 of each cereal or crop can be used for the timespan between 2017 and 2030. This is based on the same reasoning given above. As a result, average F_{plf} and F_{clf} values are reported in Table 3.3 [TurkStat, 2018a].

Table 3.3: Average values for Turkey's wheat, maize, rice and potato production losses/production and consumption losses/consumption between 2017 and 2030.

Cereal or tuber	Average value for production losses/production, %, values for 2017 and 2030 ^b , current study, F_{plf} values calculated from [TurkStat, 2018a]	Average value for consumption losses/consumption, %, values for 2017 and 2030 ^b , current study, F_{clf} values calculated from [TurkStat, 2018a]
Maize	3.0%	11.9%
Potato	1.7%	3.4%

Table 3.3: (continued).

Rice	1.0%	2.5%
Wheat	5.5%	3.7%
^b These are average values for production losses/production and consumption losses/consumption values between 2007 and 2016, which are calculated from [TurkStat, 2018a].		

Consequently, the methodology used for forecasting Turkey's potential bioethanol yield from wheat, maize, rice and potato production and consumption losses between 2017 and 2030 is explained in the next subsection.

3.3. Methodology for Forecasting Turkey's Potential Bioethanol Yield from Wheat, Maize, Rice and Potato Production and Consumption Losses between 2017 and 2030

When the production and consumption loss forecasts are available, estimation of potential bioethanol yield can be carried out using Equations (3.5) and (3.6).

$$B_{ypl}(t) = C_{pl}(t) \times B_{yoc} \times A + \varepsilon_t \quad (3.5)$$

$$B_{ycl}(t) = C_{cl}(t) \times B_{yoc} \times A + \varepsilon_t \quad (3.6)$$

In Equations (3.5) and (3.6), t is year which is ≥ 2017 , $B_{ypl}(t)$ is bioethanol yield from cereal or crop production loss in year t in litres, $B_{ycl}(t)$ is bioethanol yield from cereal or crop consumption loss in year t in tonnes, $C_{pl}(t)$ and $C_{cl}(t)$ are cereal or crop production and consumption losses in year t in litres given in Equations (3.3) and (3.4), B_{yoc} is bioethanol yield from cereal or crop in litres per tonne, A is the availability factor of the cereal or crop production and consumption losses, which is the amount that can be recovered to produce bioethanol in %, and ε_t is a "random" error term. In this thesis study, A is assumed as 100% or 1.0 in order to calculate maximum bioethanol production potentials from loss/waste streams. In addition, average B_{yoc} values given in Table 2.1 are used for calculation.

To sum up, in this section the methodology used for forecasting Turkey's wheat, maize, rice and potato production, consumption, associated losses and potential maximum bioethanol yield from these losses between 2017 and 2030 are explained in detail. Results obtained using Equations (3.1) to (3.6) and data given in Tables 2.1 to 3.3 are given in section 4, alongside with the proper scientific discussion.

4. RESULTS and DISCUSSION

4.1. Forecasting Turkey's Wheat, Maize, Rice and Potato Production, Consumption and Associated Losses in Turkey between 2017 and 2030

Results obtained in this thesis study about Turkey's per capita wheat, maize, rice and potato production and consumption are given in Figure 4.1 [TurkStat, 2018a], [TurkStat, 2018b], [TurkStat, 2018c]. As can be seen from this figure, Turkey's per capita wheat, maize, rice and potato production and consumption values vary around different average values. Therefore, average values for Turkey's per capita wheat, maize, rice and potato production and consumption between 2007 and 2016 were previously calculated and reported in Table 3.1. As explained in section 3, it is assumed that Turkey's per capita wheat, maize, rice and potato production and consumption values between 2017 and 2030 would be the same as the average values estimated between 2007 and 2016. As a result, Turkey's wheat, maize, rice and potato production and consumption forecasts between 2017 and 2030 are generated using the average per capita values given in Table 3.1, population forecasts given in Table 3.2 and Equations (3.1) and (3.2). The results are shown in Figure 4.1.

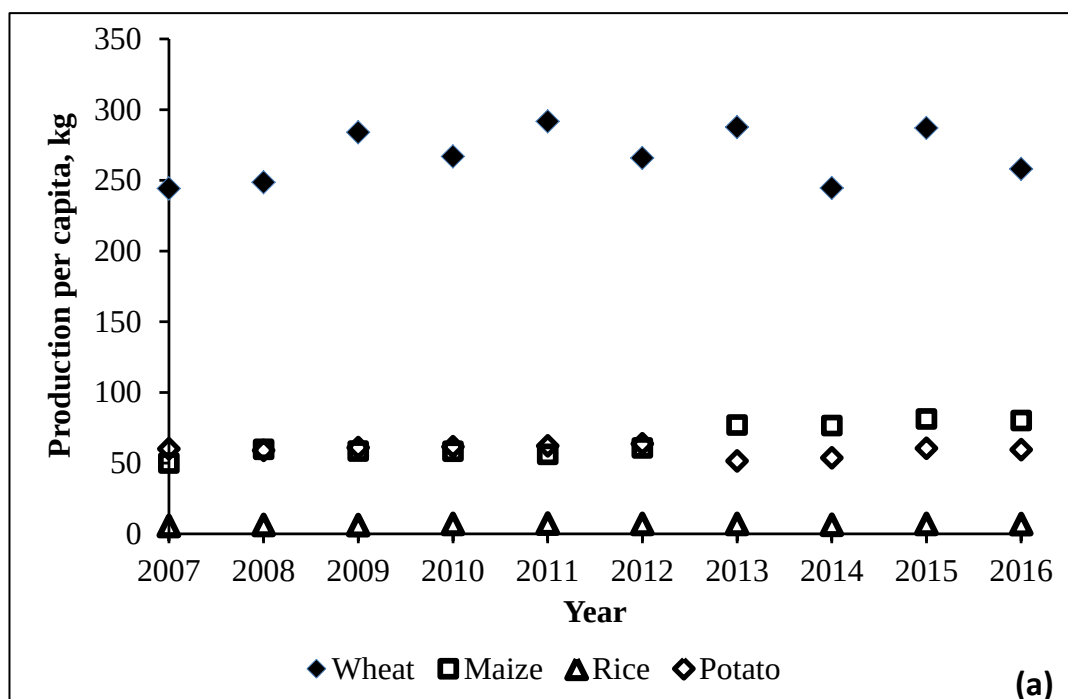


Figure 4.1(a): Wheat, maize, rice and potato production per capita in Turkey, kg.

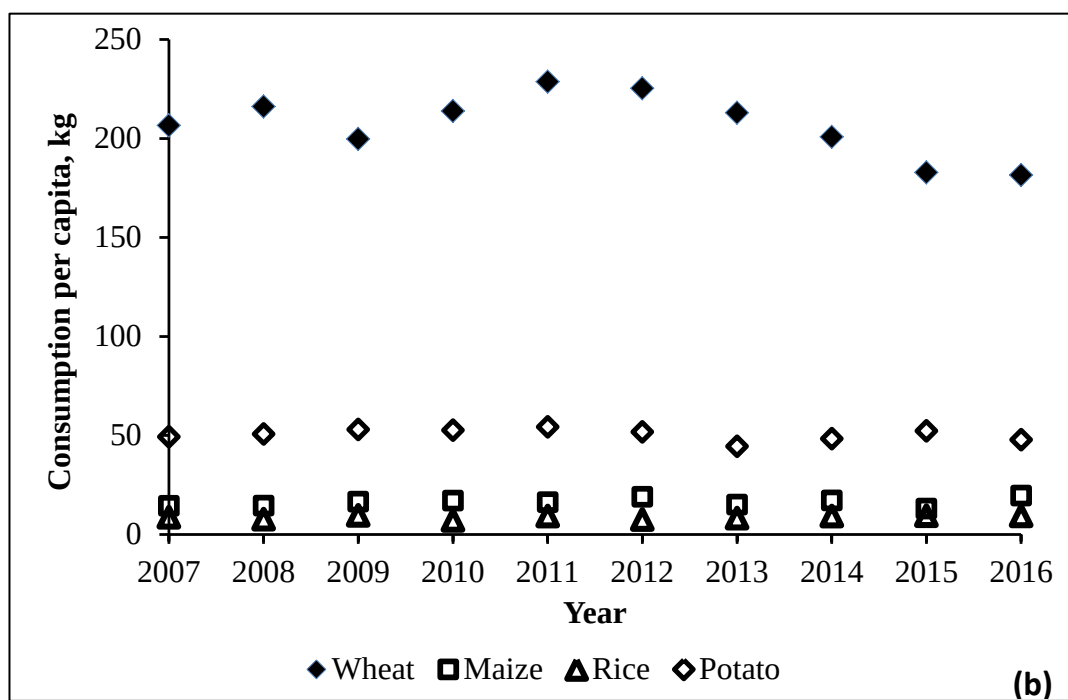


Figure 4.1(b): Wheat, maize, rice and potato consumption per capita in Turkey, kg.

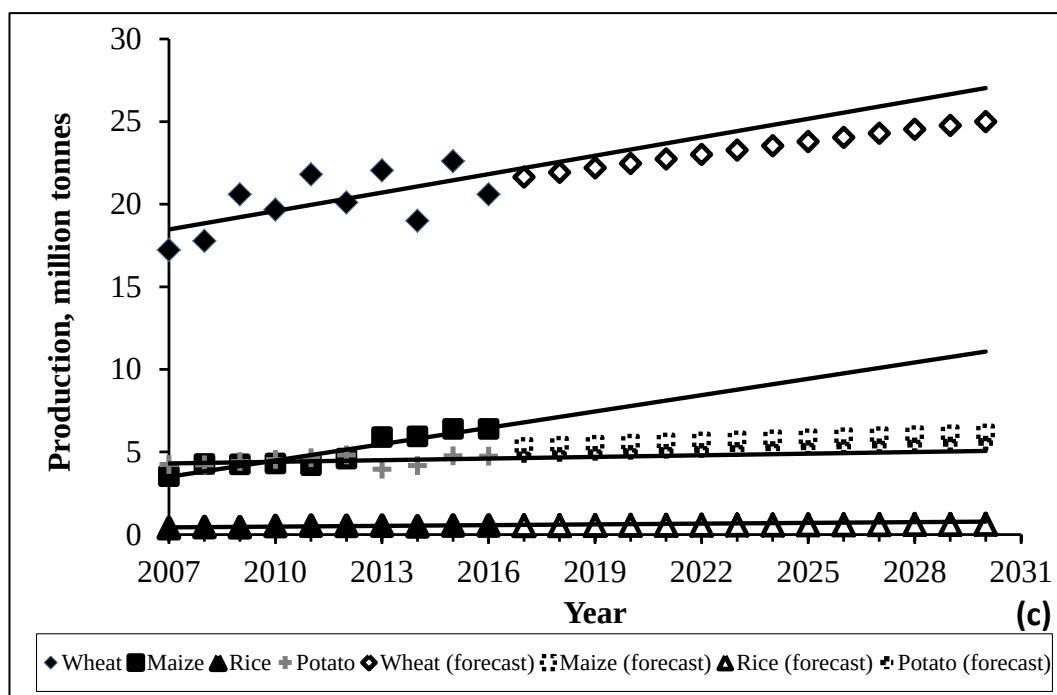


Figure4.1(c): Wheat, maize, rice and potato production forecasts in Turkey, million tonnes.

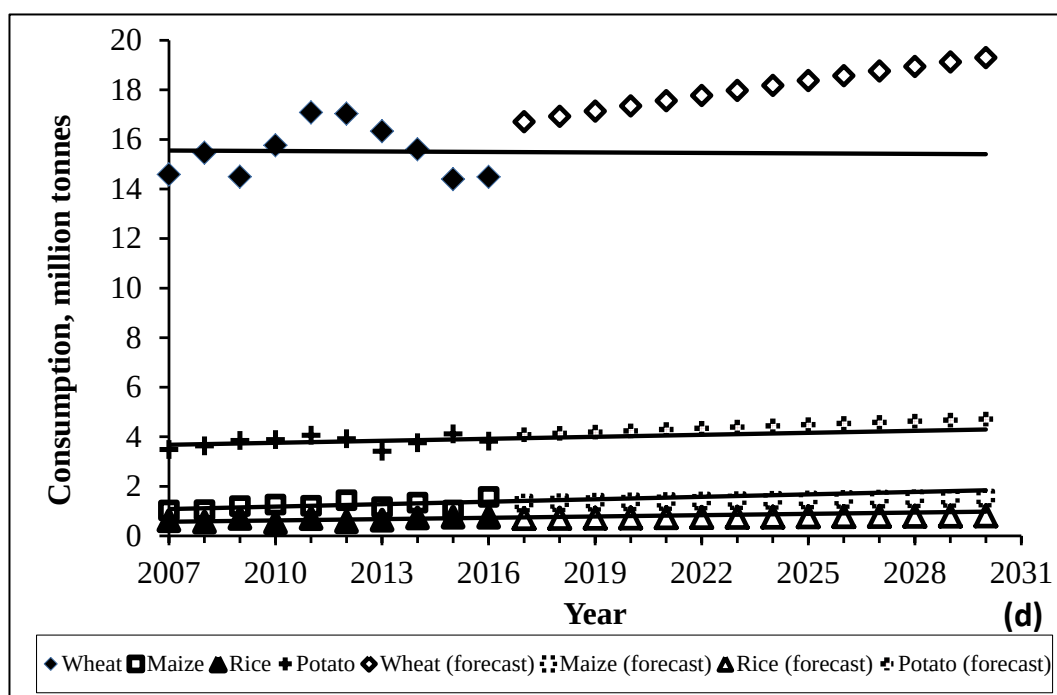


Figure 4.1(d): Wheat, maize, rice and potato consumption forecasts in Turkey, million tonnes.

As can be seen from Figure 4.1, the timeline data about production and consumption between 2007 and 2016 are linearly extrapolated (solid lines) using the

statistical functions provided by Microsoft Excel 2010. As can be seen from this figure, the forecasts generated based on per capita growth differed from those linear extrapolations. Also, the coefficients of determination, R^2 , values of these linear extrapolations are significantly lower. Here, it must be emphasized that these solid lines are generated to provide baseline data for a business as usual (BAU) scenario in order to assess the soundness of the forecasts generated in this thesis study. According to the forecasting models generated in this thesis study, it is estimated that Turkey's wheat, maize, rice and potato production in 2030 will reach to 25.0, 6.2, 0.6 and 5.5 million tonnes, respectively. Similarly, it is estimated that Turkey's wheat, maize, rice and potato consumption in 2030 will reach to 19.3, 1.5, 0.8 and 4.7 million tonnes, respectively.

According to the OECD-FAO Agricultural Outlook 2018-2027, Turkey's wheat, maize, coarse grain, rice production in 2027 are estimated at 26.223, 7.639, 9.548, 0.630, million tonnes, respectively [OECD-FAO, 2018]. Similarly, in the same publication, Turkey's wheat, maize, coarse grain, rice consumption in 2027 are estimated at 24.985, 8.826, 9.984, 0.861 million tonnes, respectively [OECD-FAO, 2018]. As a note of caution, data for potato consumption and production cannot be found the source publication [OECD-FAO, 2018]. As can be seen from the above projections, Turkey might become a net importer for maize, coarse grains and rice in the year 2027, because the production cannot supply the consumption. This is important for Turkey's food security and important point for any maize, coarse grain and rice based bioethanol production plans.

Data about losses associated with Turkey's wheat, maize, rice and potato production and consumption between 2007 and 2016 are given in Figure 3.1. As can be seen from this figure, Turkey's wheat, maize, rice and potato production losses/production values between 2007 and 2016 were assumed as constant by TurkStat and for consumption associated losses between 2007 and 2016 vary around different average values. As stated in section 3, these average values were previously calculated and reported in Table 3.3. It is assumed that Turkey's wheat, maize, rice and potato production losses/production and consumption losses/consumption values between 2017 and 2030 would be the same as the average values estimated between 2007 and 2016.

Turkey's wheat, maize, rice and potato production and consumption losses are estimated using the production and consumption forecasts given in Figure 4.1, data

in Tables 3.2 and 3.3, and Equations (3.3) and (3.4) and results are shown in Figure 4.2. As can be seen from this figure, it is estimated that Turkey's wheat, maize, rice and potato production losses in 2030 will reach to 1.375, 0.184, 0.006 and 0.094 million tonnes, respectively. Similarly, it is estimated that Turkey's wheat, maize, rice and potato consumption losses in 2030 will reach to 0.710, 0.182, 0.020 and 0.160 million tonnes, respectively.

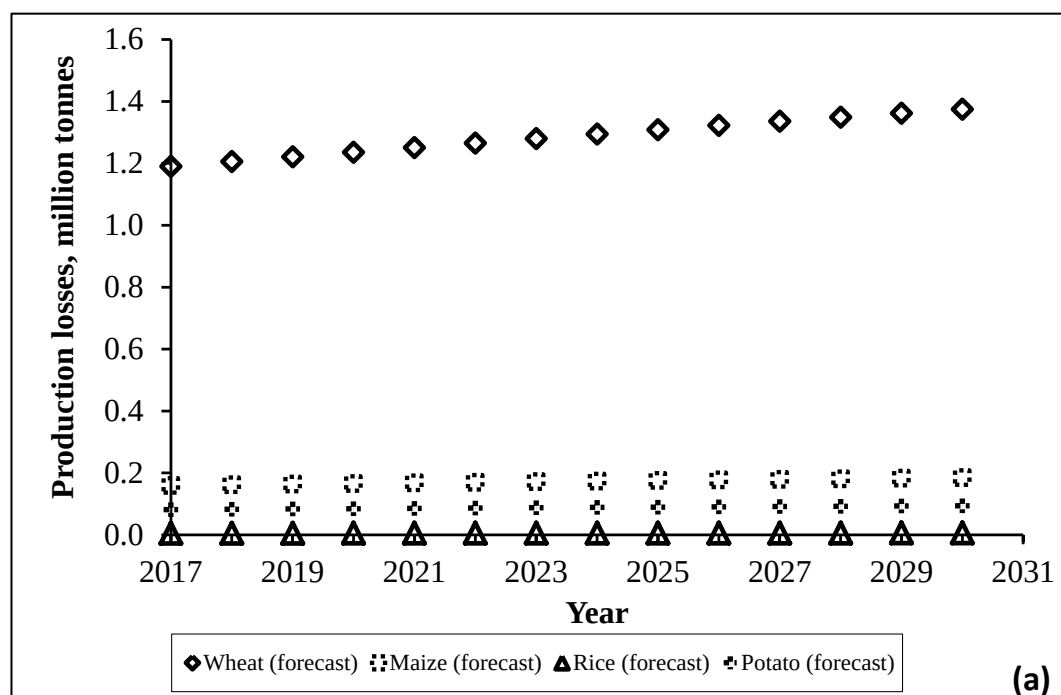


Figure 4.2: (a) Production losses forecast for wheat, maize, rice and potato in Turkey, million tonnes.

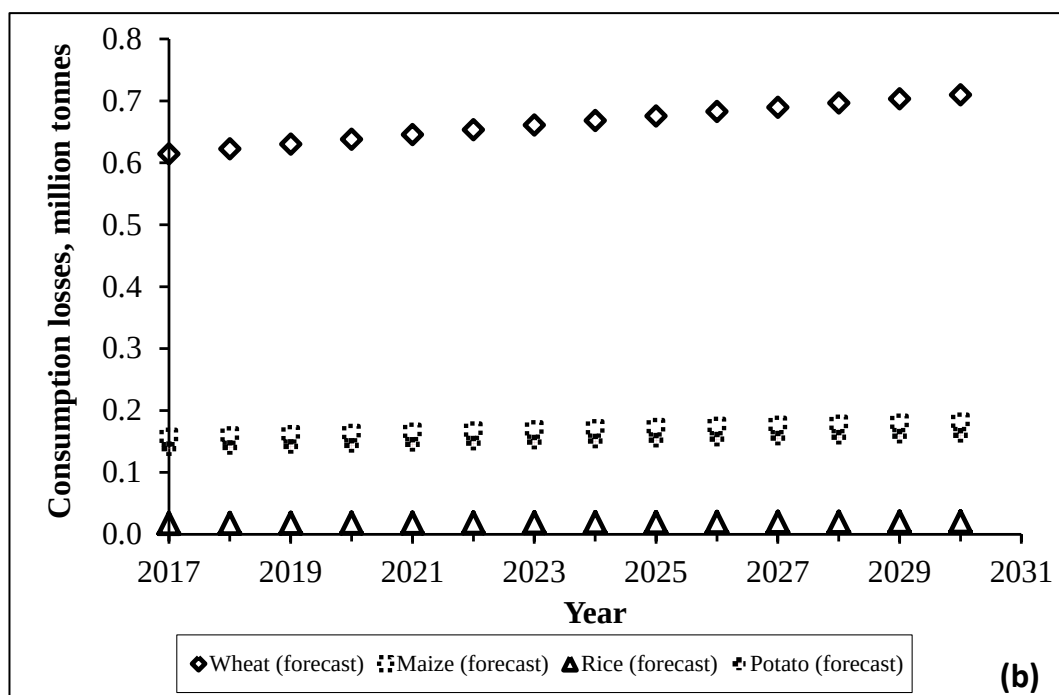


Figure 4.2(b): Consumption losses forecast for wheat, maize, rice and potato in Turkey, million tonnes.

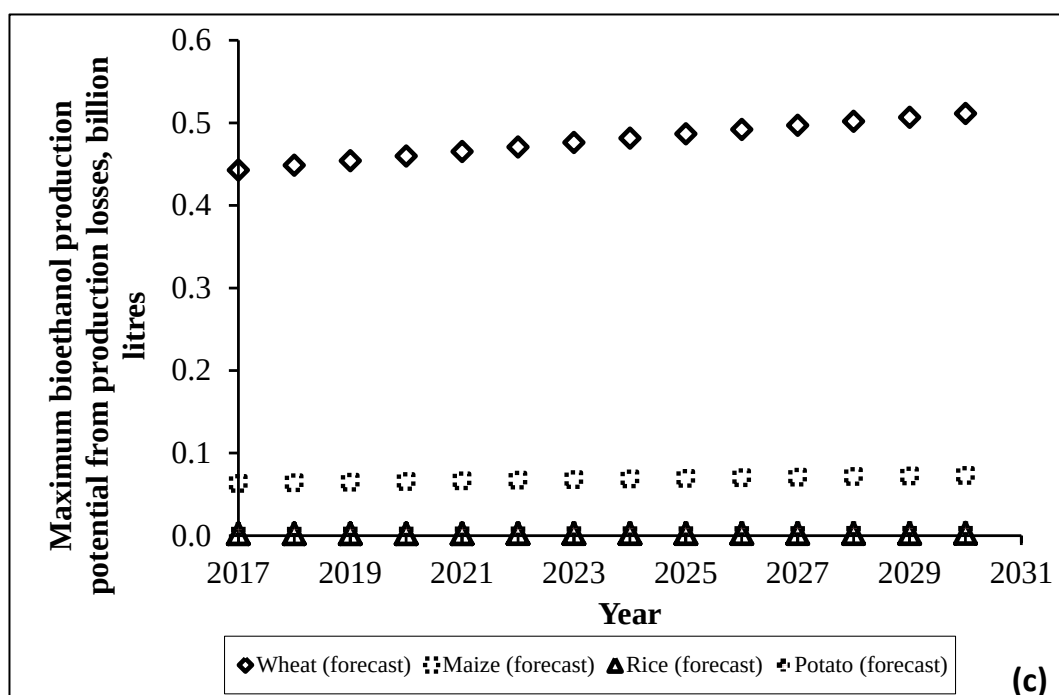


Figure 4.2(c): Maximum bioethanol production potential from production losses in Turkey, billion litres.

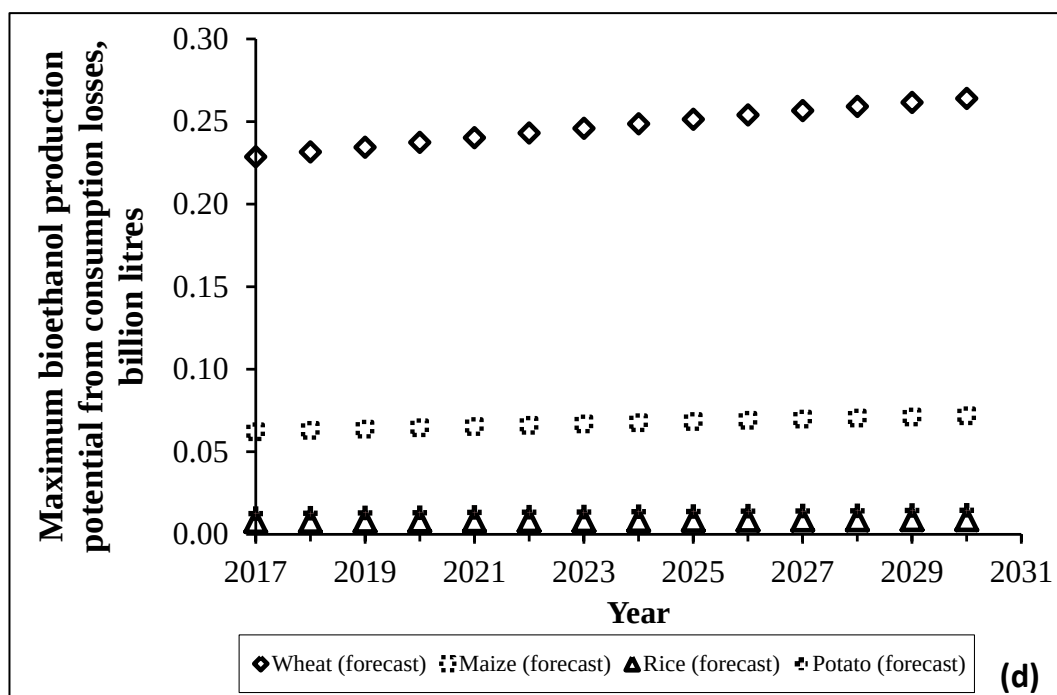


Figure4.2(d): Maximum bioethanol production potential from consumption losses in Turkey, billion litres.

During production and consumption of wheat, maize, rice and potato significant amounts are wasted in both Turkey and around the globe. In a recent study, FAO estimated part of the initial production lost or wasted at different food supply chain (FSC) stages, %, for cereals and root/tuber crops in different regions of the world [FAO, 2011]. Turkey has a unique geographical location between West Asia, North Africa and Eastern Europe. Potato is classified as a tuber and wheat, maize and rice are classified as cereals. Based on these definitions Table 4.1 was created [FAO,2011].

Table 4.1: Part of the initial production lost or wasted at different food supply chain (FSC) stages, %, for cereals and root/tuber crops in different regions of the world.

	Consumption	Distribution	Processing	Post-harvest	Agriculture	Total	Region
Cereals	22%	2%	5%	3%	2%	4%	Europe
Cereals	10%	4%	4%	7%	6%	1%	North Africa, West and Central Asia
Average	16%	3%	5%	5%	4%	3%	Estimated for Turkey due to unique geographical location

Table 4.1: (continued).

Root and tuber crops	7%	5%	12%	8%	20%	2%	Europe
Root and tuber crops	4%	2%	11%	9%	7%	3%	North Africa, West and Central Asia
Average	6%	4%	12%	9%	14%	3%	Estimated for Turkey due to unique geographical location
Note: Values given in this table are approximate values read from figures in the source publication [FAO, 2011].							

As can be seen from Table 4.1, during consumption, distribution, processing, post-harvest, and agriculture of wheat, maize and rice on average nearly 4%, 5%, 5%, 3% and 16% of the initial production can be wasted or lost in Turkey, respectively. Similarly for potatoes during consumption, distribution, processing, post-harvest, and agriculture on average nearly 14%, 9%, 12%, 4%, and 6% of the initial production can be wasted or lost in Turkey, respectively. As can be seen from Table 3.3, the losses associated with production and consumption is lower than that of the FAO estimates given in Table 4.1. Yet, Turkey generates significant amounts of wheat, maize, rice and potato waste during production and consumption, because the amount that is processed is significantly high (see Figures 3.1 and 4.1).

4.2. Forecasting Turkey's Potential Bioethanol Yield from Wheat, Maize, Rice and Potato Production and Consumption Losses

Using the results given in Figures 3.1 and 4.1, Tables 3.2 and 3.3, and Equations (3.5) and (3.6), Turkey's potential bioethanol yield from wheat, maize, rice and potato production and consumption losses between 2017 and 2030 are estimated and shown in Figures 4.2. As a note of caution, the values about bioethanol yields are the maximum attainable values because the availability, A , factors given in Equations (3.5) and (3.6) are assumed as 1.0. Collecting and processing of agricultural wastes is a main challenge in Turkey and around the world. Therefore, further research must be carried out in this field to create successful waste allocation and processing strategies. As can be seen from Figure 4.2, it is estimated that from

Turkey's wheat, maize, rice and potato production losses in 2030 up to 0.511, 0.073, 0.003, and 0.009 billion litres of bioethanol can produced, respectively. Similarly, it is estimated that from Turkey's wheat, maize, rice and potato consumption losses in 2030 up to 0.264, 0.072, 0.009, and 0.015 billion litres of bioethanol can produced, respectively.

The aforementioned amountsof bioethanol won'tbe enough for solely supplying Turkey's gasoline demand; however,they are sufficient enough to be used as an additive to gasoline for reaching a sustainable future.In a recent study, Melikoglu estimated that Turkey's bioethanol demand (as a substitute to gasoline) in 2023 would be 0.3 billion litres [Melikoglu, 2014]. As can be seen from Figure 4.2, Turkey's maximum potential bioethanol yield from wheat, maize, rice and potato production losses in 2023 is estimated as 0.476, 0.068, 0.003 and 0.008 billion litres respectively. Also, Turkey's maximum potential bioethanol yield from wheat, maize, rice and potato consumption losses in 2023 is estimated as 0.246, 0.067, 0.008 and 0.014 billion litres respectively. Therefore, if collected and processed properly in 2023 up to 0.555 and 0.335 billion litres of bioethanol can be collectively generated from Turkey's wheat, maize, rice and potato production and consumption losses, respectively. These amounts are more than enough to supply Turkey's potential bioethanol demand of 2023 based on the calculations of Melikoglu [Melikoglu, 2014].

5. CONCLUSIONS

Loss or waste generation in agricultural processing is an inevitable outcome. First generation bioethanol can be sustainable if food waste streams are utilised instead of food grade raw materials. By this way a synergistic solution can be found to food waste problem and food vs. fuel debate around 1st generation bioethanol production. In this thesis study, Turkey's wheat, maize, rice and potato production, consumption, associated losses and bioethanol yield from these streams are estimated till 2030. It is forecasted that Turkey's wheat, maize, rice and potato production in 2030 will become 25.0, 6.2, 0.6 and 5.5 million tonnes, respectively. Similarly, it is forecasted that Turkey's wheat, maize, rice and potato consumption in 2030 will become 19.3, 1.5, 0.8 and 4.7 million tonnes, respectively. It is also calculated that Turkey's wheat, maize, rice and potato production losses in 2030 will become 1.375, 0.184, 0.006 and 0.094 million tonnes, respectively. Similarly, it is calculated that Turkey's wheat, maize, rice and potato consumption losses in 2030 will become 0.710, 0.182, 0.020 and 0.160 million tonnes, respectively. Also, it is estimated that from Turkey's wheat, maize, rice and potato production losses in 2030 up to 0.511, 0.073, 0.003, and 0.009 billion litres of bioethanol can produced, respectively. Similarly, it is estimated that from Turkey's wheat, maize, rice and potato consumption losses in 2030 up to 0.264, 0.072, 0.009, and 0.015 billion litres of bioethanol can produced, respectively.

There are no projections about Turkey's potential bioethanol yield from wheat, maize, rice and potato production and consumption losses in the literature. Therefore, it is estimated that if collected and processed properly, in 2023, up to 0.555 and 0.335 billion litres of bioethanol can be collectively generated from Turkey's wheat, maize, rice and potato production and consumption losses, respectively; and these amounts will be more than enough to supply Turkey's potential bioethanol demand of 2023, which was previously estimated as 0.3 billion litres by Melikoglu[Melikoglu, 2014].

Finally, it is believed that the methodology given in this thesis study can be used by researchers and policy analysts around the globe to generate nationwide bioethanol generation scenarios from wasted crops and cereals.

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