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A THESIS SUBMITTED FOR THE DEGREE OF
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GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

TÜRKİYE'DE 2030 YILINA KADAR ATIK PİŞİRME YAĞLARINDAN BİYODİZEL ÜRETİMİNİ TAHMİN ETMEK VE SÜRDÜRÜLEBİLİRLİĞİNİ ANALİZ ETMEK, İLGİLİ KARAR DESTEK ARAÇLARI VE SÜRDÜRÜLEBİLİRLİK SENARYOLARI OLUŞTURMAK

AYÇİN MÜYESSER CİNEL
YÜKSEK LİSANS TEZİ
KİMYA MÜHENDİSLİĞİ ANABİLİM DALI

DANIŞMANI
DOÇ. DR. MEHMET MELİKOĞLU

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2019

GEBZE TEKNİK ÜNİVERSİTESİ	**YÜKSEK LİSANS JÜRİ ONAY FORMU**

GTÜ Fen Bilimleri Enstitüsü Yönetim Kurulu'nun 19/06/2019 tarih ve 2019/27 sayılı kararıyla oluşturulan jüri tarafından 03/07/2019 tarihinde tez savunma sınavı yapılan Aycin Müyesser CİNEL'ın tez çalışması Kimya Mühendisliği Anabilim Dalında YÜKSEK LİSANS tezi olarak kabul edilmiştir.

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Gebze Teknik Üniversitesi Fen Bilimleri Enstitüsü Yönetim Kurulu'nun ....../....../......... tarih ve ..../........ sayılı kararı.

SUMMARY

The aim of this thesis study is to calculate Turkey's biodiesel production potentials from cooking oil (specifically sunflower oil) wastes till 2030, and calculate potential environmental and economic savings such as water pollution prevention and income generations based on different bioconversion routes and scenarios. In addition, a decision support tool and sustainability scenarios are generated to reduce waste cooking oil generation and effective reutilization for biodiesel production.

Biodiesel production from sunflower oil consumption wastes is projected to be nearly 190.3, 244.9, and 313.7 million litres in 2030 based on 2.0%, 4.0% and 6.0% annual increases in sunflower consumption per capita, respectively. Likewise, it is projected that biodiesel production from Turkey's sunflower oil consumption wastes in kg and million litres, diesel equivalent of these productions in litres and their potential net in TL will be (i) 166,438,433 kg, 190.3 million litres, 175,398,310 litres, and 1,052,389,860 TL in 2030 based on 2.0% annual increase in sunflower consumption per capita, (ii) 214,232,224 kg, 244.9 million litres, 225,764,983 litres, and 1,354,589,899 TL in 2030 based on 4.0% annual increase in sunflower consumption per capita, and iii) 274,427,503 kg, 313.7 million litres, 289,200,753 litres, and 1,735,204,520 TL in 2030 based on 6.0% annual increase in sunflower consumption per capita, respectively. Finally, water pollution potential of sunflower oil consumption wastes in Turkey is projected to reach 4,523, 5,822, 7,457 million m^3 in 2030 based on 2.0%, 4.0% and 6.0% annual increases in sunflower oil consumption per capita, respectively.

Key Words: biodiesel, economic analysis, decision support tool, sunflower oil, water pollution, sustainability scenario.

ÖZET

Bu tez çalışmasının amacı, 2030 yılına kadar Türkiye'nin atık yemeklik yağlardan (özellikle ayçiçek yağı) biyodizel üretim potansiyelini hesaplamak, ve su kirliliğini önleme ve gelir getirileri gibi potansiyel çevresel ve ekonomik tasarrufları farklı biyolojik dönüşüm yollarına ve senaryolara dayanarak hesaplamaktır. Ayrıca, atık yemeklik yağ üretimini azaltmak ve biyodizel üretimi ve yeniden kullanımını etkinleştirmek için bir karar destek aracı ve sürdürülebilirlik senaryoları oluşturulmuştur.

Ayçiçek yağı tüketim atıklarından biyodizel üretiminin, 2030 yılında, ayçiçeği tüketiminde kişi başına yıllık %2,0, %4,0 ve %6,0 artışa bağlı olarak yaklaşık sırasıyla 190,3, 244,9 ve 313,7 milyon litre olabileceği hesaplanmıştır. Aynı şekilde, Türkiye'nin ayçiçek yağı tüketim atıklarından elde edilebilecek biyodizel üretiminin kg, milyon litre, bu üretimlerin litre cinsinden dizel eşdeğeri ve TL cinsinden potansiyel meblağları sırasıyla; (i) ayçiçeği tüketimindeki kişi başına yıllık %2,0 artışa bağlı olarak 2030'da; 166.438.433 kg, 190,3 milyon litre, 175.398.310 litre ve 1.052.387.860 TL'dir (ii) ayçiçeği tüketiminde kişi başına yıllık %4,0 artışa bağlı olarak 2030'da; 214.232.224 kg, 244,9 milyon litre, 225.764.983 litre ve 1.354.589.899 TL, ve iii) ayçiçeği tüketiminde kişi başına yıllık %6,0 artışa bağlı olarak 2030'da; 274.427.503 kg, 313,7 milyon litre, 289.200.753 litre ve 1.735.204.520 TL olduğu tahmin edilmektedir. Son olarak, Türkiye'de ayçiçeği yağı tüketim atıklarından kaynaklı su kirliliği potansiyelinin 2030 yılında, ayçiçeği yağı tüketiminde kişi başına %2,0, %4,0 ve % 6,0 yıllık artışa bağlı olarak sırasıyla; 4.523, 5.822, 7.457 milyon m^3 olduğu tahmin edilmektedir.

Anahtar Kelimeler: biyodizel, ekonomik analiz, karar destek aracı, ayçiçek yağı, su kirliliği, sürdürülebilirlik senaryosu.

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Finally, I have to spare my biggest appreciations for my little boy Mete Cinel. I thank God that I have him.

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LIST of ABBREVIATIONS and ACRONYMS

Abbreviations and Acronyms		**Explanations**
A	:	The availability factor of sunflower oil consumption losses
B20	:	Diesel Fuel Containing 20.0% Biodiesel
B30	:	Diesel Fuel Containing 30.0% Biodiesel
B5	:	Diesel Fuel Containing 5.0% Biodiesel
$B_{yfcl}(t)$	:	Biodiesel yield from sunflower oil consumption losses in year t in litres
B_{yoc}	:	Biodiesel yield in kg per kg of waste sunflower oil
CO	:	Carbon Monoxide
CO_2	:	Carbon Dioxide
EC_b	:	Energy content of biodiesel in MJ/L
EC_d	:	Energy content of diesel in MJ/L
g	:	Gram
kg	:	Kilogram
L	:	Liter
m^3	:	Cubic Meter
MJ	:	Megajoule
NO	:	Nitrogen Oxide
$NW_{b2018}(t)$	:	Net value of biodiesel in TL in year t based on average diesel price at the end of 2018
P(t)	:	Population at year t in number of people
$P_d(t)$	:	Average price of diesel in TL in year (t)
SO_c (t)	:	Sunflower oil consumption at year t in tonnes
$SO_{cpc}(t)$	:	Sunflower oil consumption per capita at year t in kg
$SO_{wt}(t)$	:	The total amount of sunflower oil waste generated at year t in tonnes
$SO_{wtc}(t)$	:	The total amount of sunflower oil waste generated from consumption routes at year t in tonnes
$WF_a(t)$	:	Sunflower oil waste fraction for agriculture at year t in

		%,
$WF_c(t)$	:	Sunflower oil waste fraction for consumption at year t in %
$WF_d(t)$	:	Sunflower oil waste fraction for distribution at year t in %
$WF_p(t)$	:	Sunflower oil waste fraction for processing at year t in %
$WF_{ph}(t)$	:	Sunflower oil waste fraction for postharvest at year t in %,
ε	:	A "random" error term.
ρ_b	:	Biodiesel density
CDM	:	Clean Development Mechanism
COD	:	Chemical Oxygen Demand
DST	:	Decision Support Tool
EC	:	The European Commission
EU	:	The European Union
FAO	:	Food and Agriculture Organization of the United Nations
FFA	:	Free Fatty Acids
FSC	:	Food Supply Chain
GHG	:	Green House Gas
LCA	:	Life Cycle Analysis
LPG	:	Liquefied Petroleum Gas
MCT	:	Turkey's Ministry of Customs and Trade
NGO	:	Non-governmental Organizations
OECD	:	Organization for Economic Co-operation and Development
SCT	:	Special Consumption Tax
TL (or TRY)	:	Turkish Lira's
UNEP	:	The United Nation Environment Programme
US$	:	United States Dollar
USA	:	United States of America
VAT	:	Value Added Tax

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1. INTRODUCTION

Nowadays, renewable energy sources are wanted more than fossil fuels due to increasing global energy demand and environmental concerns. Biodiesel, which is a type of biofuel, has an important role in our global energy market. Road transportation is critically important for our global economy because it supports the delivery of products to the end users (consumers). In addition, people use cars and buses for short and long distance travel. Diesel and gasoline are the two main types of transportation fuels in the market. The third one is liquefied petroleum gas (LPG). However, consumption of this is not as common as the previous two. In Turkey and around the world, majority of small and large size trucks and buses are diesel powered. In addition, for efficiency a significant portion of the cars have diesel engines instead of gasoline. However, increased consumption of diesel in cars and buses creates two major problems: (i) economic and (ii) environmental. Since the topic of interest is global (too complex to study) this thesis will focus on its aspects in Turkey.

Turkey imports most of the petroleum it consumes. As a result, increased consumption of diesel means increasing costs. Also, the price of diesel (and gasoline) is affected from the Turkish Lira's (TRY or TL) performance against the United States Dollar (US$). If US$ becomes more valuable than the TL then the price of diesel in Turkey hikes (open market economy). In Turkey, the price of diesel reached to 6.40 TL in November 2018, which is a record high [Web 1, 2019]. This was due to the fluctuation of TL against the US$ in the same period. These price shifts can only be prevented if Turkey has its own petroleum reserves, which is not the case. Luckily, today there is an alternative. That is production of biofuels from indigenous raw materials. This concept if becomes fully sustainable can lead to a bio-based economy and replace current petrochemical based system.

Biodiesel production from indigenous raw materials will also decrease Turkey's diesel associated greenhouse gas emissions. From life cycle analysis (LCA) perspective biodiesel production from wastes and fuel crops is highly beneficial compared to the petrochemical (refinery) based alternative (diesel). The conversion process of any waste into useful energy and effective utilization of it is related to technological and economic development.

In Turkey, energy demand and food waste generation are increasing. Therefore, the issue of food waste management is of great importance for our country's development and environmental priorities. Utilization of food wastes for the production of value added commodities is a relatively new topic. It is obvious that in Turkey or anywhere else production of biofuels from food wastes has both economic and environmental gains. Waste cooking oil generation is a major problem for Turkey because when dumped to sewers waste cooking oil pollutes water resources and creates unrecoverable environmental problems. Since the vegetable oil topic is too broad in this study the focus is given to the utilization of sunflower oil waste.

The Turkish cuisine is famous with its vegetable oil consumption. Almost in every meal there is one or more dish that is prepared using vegetable oil. Sunflower is the most consumed, which is followed by olive oil. The fried food market almost exclusively uses sunflower oil. In Mediterranean countries, it is estimated that nearly 5 kg of vegetable or animal oil waste is generated per capita per annum [Öztürk, 2018]. In Turkey, waste vegetable oils from food industry (i.e. frying oil) must be collected and disposed properly according to the rules and regulations. This means that large scale waste vegetable oil producers are willing to get rid of their wastes in an economically feasible manner. In addition, at homes and residences Turkish families consume significant amounts of vegetable oil. Olive oil is not used for frying mostly due to its price (expensive). As a result, waste olive generation at households is significantly lower. However, for sunflower oil this is totally different. Turkish people like fried foods and in majority of households sunflower oil is used for frying and cooking. There is no supervision at houses for waste sunflower oil disposal. As a result, a significant portion of waste sunflower oils at residences are dumped via drains. This causes major environmental problems. This problem can be solved if there is some kind of reward mechanism (money) for waste cooking oil collection. Parallel to this idea, novel decision support tools and sustainability scenarios for waste cooking oil collection and reutilization is conceptualized in this thesis study for Turkey.

In Turkey, there has been a significant increase in vegetable oil consumption for frying due to nationwide distribution of fast food chains and increasing outside eating habits. Waste vegetable oil collection is a social responsibility because of its environmental hazards (mostly underground water pollution).

Waste vegetable oils have high chemical oxygen demand (COD) values [Öztürk, 2018]. Waste vegetable oils cover the water surface when they are poured into water due to density difference; they pollute or even clog sewage system, irreversible damage the ecosystem (from microorganisms to fishes, birds and other species), prevent oxygen transfer from air to water, and affect oxygen replenishment (consequently affects oxygen depletion).

Due to the aforementioned disadvantages, in developed or developing countries (like Turkey) it is forbidden to dispose waste vegetable oil into sewage and/or water sources (both underground and surface) and there are strict economic and legal penalties (mostly for food industries). However, associated waste water pollution (due to vegetable oil disposal) in developed and developing countries is not as low as expected. For example, as mentioned above, waste vegetable oil disposal in Turkey is a major problem even though there are rules and regulations to prevent it.

Waste cooking oil generation is a major problem for Turkey. When disposed without control 1 liters of waste cooking oil can pollute up to 1,000,000 liters of fresh water [Öztürk, 2018]. As a note of caution, this estimate is relatively high and in the next sections of this thesis moderate and accurate data is found from biodiesel producers and used accordingly. Therefore, collection of waste cooking oils is at utmost importance for the environment and economy.

In this thesis study, waste cooking sunflower oil collection and processing for biodiesel production is conceptualized. When waste cooking oils are collected properly then they can be converted into biodiesel, which can be blended with diesel for fueling cars, trucks and other road vehicles. Collection of waste cooking oils from households is a major problem in Turkey, where most of it is disposed from kitchen sinks into drains. Creating mechanisms for sustainable recollection of waste cooking oils can be managed via decision support tools and sustainability scenarios. In addition, waste cooking oil generation in Turkey should be forecasted in order to analyze the size of the problem and make a sustainability analysis for the future. This forecast can be made based on per capita food waste generation models and a related decision support tool can be constructed from chemical and bioprocess engineering perspective. As a result, in this thesis study, Turkey's waste cooking (sunflower) oil generation and potential biodiesel production till 2030 is estimated via appropriate per capita waste cooking oil generation models.

The aim of this study is to carry out a feasibility study for the calculation of biodiesel production from waste cooking (sunflower) oil in Turkey till 2030; calculate potential environmental savings and value (money/cost) generations potentials based on different bioconversion routes and scenarios; and generate a decision support tool to reduce waste cooking oil generation and/or effective collection of it. The information about this subject is scarce in the published literature. As a result, this thesis is aimed to fill this gap in the literature and provide valuable information to other researchers.

Valuable and novel information about waste cooking (sunflower) oil generation and reutilization for biodiesel production for Turkey is given in this thesis study. Since must of the studies in this field focus on a single aspect of biodiesel production this in-depth study will provide the detailed information in the subject of interest. The research is carried out mostly from a chemical/bioprocess engineering perspective, which will help the development of detail economic, engineering, feasibility and sustainability analysis that can be used in future studies. Also, generation of a decision support tool will help excelling knowledge in waste reduction or waste to energy schemes. Finally, this thesis has the following sections: introduction, literature review, decision support tool and scenario development, results and discussion, conclusions.

2. LITERATURE REVIEW

2.1. Introduction

The limited availability of conventional energy sources has accelerated the search for alternative fuels [Alptekin and Çanakçı, 2006]. Biodiesel is an alternative to diesel, which is indispensable in the transportation sector both around the globe [Alptekin and Çanakçı, 2006] and in Turkey. Biodiesel can be produced from vegetable or animal oils. As stated prior, this thesis study focuses on the vegetable oil aspect of biodiesel production. To be specific the waste portion of sunflower oils. When vegetable oils (cooking) are poured into drains and enter to the sewage system, they damage the sewage system and seriously pollute the water ecosystem (waste water). As a note, from here onwards, in this thesis study waste vegetable oils cover wasted vegetable oils both cooked and raw (uncooked). Therefore, recovery of waste vegetable oils is at utmost importance. And, when they are recovered, their damage to the environment is minimized. Current, regulations in Turkey dictate that companies that produce significant amounts of waste vegetable oil must properly dispose them. One of the most feasible options is to give these waste vegetable oils to licensed biodiesel producers.

2.2. Vegetable Oil Consumption in Turkey/Waste and Biodiesel Production Routes

In Turkey, each year nearly 1.5 million tonnes of vegetable oil is used for cooking and catering and approximately 150,000 tonnes of waste vegetable cooking oil is generated per annum [Öztürk, 2018]. Here, it must be specified that this is one estimation from a specific reference; as the thesis develops other estimates from the literature will be given. Waste cooking oils can be converted into biodiesel according to the following diagram given in Figure 2.1, which is drawn from the explanations of the following references [PSU, 2018], [Öztürk, 2018]. As can be seen from Figure 2.1, approximately 100 kg of biodiesel and 10 kg of glycerin can be produced from 100 kg of waste vegetable oil. Although the values given in Figure 2.1 are stoichiometric, the typical conversion values are also in very close vicinity. As a result, in this thesis study the stoichiometric and typical waste vegetable oil to biodiesel conversion are assumed to be the same. That is 1.0 kg biodiesel plus 0.1 kg glycerin can be produced from 1.0 kg waste vegetable oil.

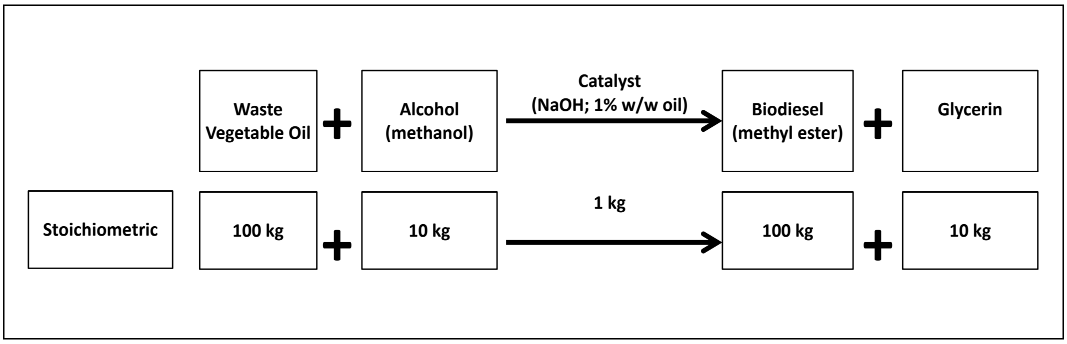

Figure 2.1: Conversion of waste vegetable oil into biodiesel.

Each year up to 150,000 tonnes of biodiesel can be produced from Turkey's wasted vegetable oils and, by doing so, wastewater pollution can be reduced [Öztürk, 2018]. In recent years, research on alternative energy sources such as biodiesel has become increasingly important in Turkey [Melikoğlu, 2014]. The main reasons for this are economic and environmental. Turkey's petroleum based road transportation fuel (diesel and gasoline) has been increasing in the last couple of years and as stated in the introduction section of this thesis reached to record levels in 2018. As a result, authorities in Turkey want to promote local alternatives to diesel and gasoline. Biodiesel production from waste vegetable oils has multiple benefits, including wastewater pollution control and reduced diesel consumption (both economic and greenhouse gas emission reductions) [Melikoğlu, 2014].

Biodiesel is produced from local resources; it is non-toxic; renewable and biodegradable and most importantly direct alternative to the diesel sold in the market. In addition, biodiesel has been shown to play an important role in reducing environmental pollution by reducing greenhouse gas emissions [Moecke et al., 2016], [Singh and Singh, 2010]. Also, through biodiesel, there has been a significant decrease in CO, CO_2 and NO emissions to the environment [Dorado et al., 2003]. Vegetable oils are very good raw materials for biodiesel production due to their free fatty acids and biochemical composition [Zhang et al., 2003a]. Zhang and friends have reduced the cost of raw materials by using waste oils to produce biodiesel [Zhang et al., 2003b]. As a result of these studies, it has been observed that waste vegetable oils (frying) can be used as an environment-friendly alternative for biodiesel production [Cubas et al., 2016]. These findings from the literature clearly support the research idea, which is investigated in this thesis study.

In another study, it is estimated that nearly 350,000 tonnes of waste oil is generated in Turkey per annum [Alptekin and Çanakçı, 2006]. This is more than twice of Öztürk's estimate given above [Öztürk, 2018]. According to this study, if these waste oils are collected and utilized for biodiesel production, nearly 480 million TL will be saved annually [Alptekin and Çanakçı, 2006]. In addition, when these waste oils are utilized for biodiesel production, Turkey's greenhouse gas emissions from diesel consumption will be reduced by nearly 900,000 tonnes of CO_2 equivalent [Alptekin and Çanakçı, 2006]. This clearly shows that there are several estimates about waste oil generation in Turkey. As a result, in this thesis study, a new estimate is made based on well-known and highly cited references found from the literature. Details of this are given at the end of this section.

Turkey is an emerging and developing economy. Most of the commodities are transported with roads and diesel consumption is increasing. Yet, most of it is produced from imported petroleum. Therefore, biodiesel production from waste vegetable oils will help Turkey's economy and if produced in bulk, in that case it won't be from waste streams but from designated oilseed plants, can be sold at relatively lower prices. In this thesis, study the aim is to show the potential benefits of biodiesel production from waste vegetable oil and it must be clearly emphasized that the aim is food waste reutilization not finding a direct alternative to diesel consumption.

The second main output of biodiesel production is glycerin (Figure 2.1). A basic factor in the cost of biodiesel generation is the economic evaluation of glycerin [Sabancı et al., 2010]. Glycerin, which is obtained as a by-product, can be evaluated in soap and cosmetics industry and can be purified and used in the pharmaceutical industry [Sabancı et al., 2010]. This means that if collected and processed properly other value added products can be generated from waste vegetable oils.

Biodiesel production in Turkey can be promoted via incentives, including provision of tax deductions and insurance premium payments by supporting the logistics sector [Erdoğan and Keskin, 2015]. Other options may be Value Added Tax (VAT) exemptions, VAT refunds, low interest rate funding for investments in the logistic sectors [Erdoğan and Keskin, 2015]. It is possible and more beneficial to apply these investments first to the bio refinery sector then to the logistics. By this way production of biodiesel can be promoted and then its consumption will be guaranteed by the logistics sector. This would be a win-win scenario for the producers and consumers. Likewise, these promotions must be at national level rather than local supports for certain regions/areas [Erdoğan and Keskin, 2015].

The European Commission (EC) currently recommends the use of diesel fuel containing 5.0% biodiesel (this also known as B5, which is 5.0% biodiesel and 95.0% petroleum based diesel), but recommends that this rate may be increased to 20.0% (B20) in 2020 and to 30.0% (B30) in 2030 [Köse, 2009]. The European Union (EU) aims to provide 4.0% of global fuel consumption (transportation sector) from biofuels until 2030 [Köse, 2009]. Biodiesel alongside with bioethanol will have major roles to achieve such an ambitious target.

As stated above, waste cooking oils used as methyl esters can be used as biodiesel in Turkey [Utlu, 2005]. This can create new business opportunities and reduce environmental pollution arising from these oils [Utlu, 2005]. However, the biggest problem in the evaluation of these oils is collection and processing [Utlu, 2005]. Therefore, in this thesis study, decision support tools and sustainability scenarios addressing these major problems will be given as a part of the solution.

As a part of the sustainability scenarios and decision support tools the first step is increasing awareness of the public about the waste cooking oil problem. In a recent study, when awareness of housewives, students and tradesmen regarding collection of waste vegetable oils and biodiesel is raised then the amount of waste oil collection increased [Sağır, 2018]. The participation rate in the waste oil campaign was 0.2% (The province of Trabzon is taken as a basis in the district of Ortahisar) [Sağır, 2018]. In the same study, the following observations were made: (i) 35%-45% of participants (secondary school, high school and university students) did not know that waste oil has been collected by municipalities; (ii) 32%-55% of participants (secondary school, high school and university students) know that fuel can be obtained from waste cooking oils [Sağır, 2018]. An important finding of this study is revealed by the Turkish housewives; they stated that 80% of them use 1 liter of vegetable oil per weak, and the remainder 20% uses 2 liters of vegetable oil per weak [Sağır, 2018].

It was reported that annually 1.7 million tonnes of vegetable oils is used in Turkey [Behçet et al., 2012]. Details of sunflower oil consumption will be given in the following parts of this subsection. According to Behçet and co-workers waste vegetable oils must be recovered for biodiesel production in order to reduce their damage to the environment [Behçet et al., 2012]. They concluded that biodiesel obtained from waste frying oils, have similar engine performance and exhaust emission values with petroleum based diesel [Behçet et al., 2012].

There are certain studies in the literature that focuses on the estimation of biodiesel requirement as an additive to diesel. Such studies focus on the estimation of Turkey’s diesel consumption in the following years and then calculate the potential biodiesel demand. One of these studies was carried out by Melikoğlu in 2014. In this study, the author calculated that nearly 1.4 million m^3 of biodiesel could be required to match the official targets in 2023 [Melikoğlu, 2014]. Therefore, significant amounts of biodiesel must be produced from vegetable oils either food grade or waste. Here, utilization of waste cooking oils would be highly beneficial.

Biodiesel is a proven alternative to diesel for transportation and it is has better fuel properties it is renewable, biodegradable, and non-toxic [Yaakob et al., 2013]. Waste frying oils have suitable characteristics for transesterification and its utilization is an effective way to reduce the raw material cost and reduce associated pollution problems [Encinar et al., 2005].

Biodiesel (100%) and diesel-biodiesel mixtures can be used in diesel engines [Yıldız, 2008]. Biodiesel’s negative effect on the ozone layer is assumed to be 50% less than that of petroleum based diesel fuel [Yıldız, 2008]. Since sulfur components in biodiesel fuels are almost negligible related atmospheric pollution can be eliminated such as acid rains due to increased consumption of petroleum based diesel fuel in cities [Yıldız, 2008]. In terms of performance, biodiesel has similar engine performance characteristics with petroleum based diesel [Güler, 2008].

Transesterification is the most popular method for producing biodiesel from different oils (non-petroleum) [Kılınçlı, 2011]. All vegetable oils and animal fats primarily contain triglyceride molecules [Kılınçlı, 2011]. By transesterification (process) those triglycerides (the main components of oil) are converted to their corresponding mono alkyl esters [Kılınçlı, 2011]. Transesterification of triglycerides involves using a short chain alcohol (like methanol) in the presence of a suitable catalyst resulting in the production of biodiesel and the by-product glycerol [Kılınçlı, 2011]. As given in Figure 2.1, the transesterification (process) steps are in order: alcohol and catalyst mixing, reaction, separation, finally methyl ester washing [Yılmaz, 2017]. The benefits of the transesterification processes to oils are: complete removal of glycerides, decrease in boiling point, decrease in flash point, increase in fluidity rate, reduced viscosity [Yılmaz, 2017].

As stated above, glycerin is released from biodiesel production as a by-product. As shown in Figure 2.1, almost 10 kg of glycerin is formed for every 100 kg of waste vegetable oil is converted into 100 kg of biodiesel. For small volumes this might be considered as negligible. However, when volumes about multiple thousand tonnes are reached than the produced glycerin become a major problem and a sustainable solution for its proper disposal or reutilization must be found. Glycerin can be purified by various processes [Uysal, 2006]. In Turkey, glycerin consumption is nearly 20 thousand tonnes per annum in Turkey [Uysal, 2006]. Glycerin has various uses such as in the soap industry, cosmetics, pharmaceutical industry, food industry, resin industry, paper industry and etc. [Uysal, 2006].

Annual vegetable oil consumption in Turkey is in multimillion tonnes region and waste generation is immense [Oğuz, 2007]. However, recycling of vegetable oil wastes is not an easy task [Oğuz, 2007]. In Turkey, waste vegetable oil generation can be up to 1.5 million tonnes per annum; however, up to 300-350 thousand tonnes of this can be potentially recycled per annum [Oğuz, 2007].

In order to recycle waste vegetable oils, oil traps have been developed [Oğuz, 2007]. They are connected to the sinks to keep waste oils [Oğuz, 2007]. They separate oil and water according to density difference with physical methods [Oğuz, 2007]. However, these are not wide-spread in Turkish households. In reality, they are very seldom used. Industrially, the waste vegetable oils obtained from the oil holders contain high amounts of water and sediment [Çanakçı, 2011].

Vegetable waste oils from oil traps contain more free fatty acid (FFA) than directly collected waste vegetable oils [Çanakçı, 2011].

FFA content of waste cooking vegetable oils is higher than that of fresh vegetable oils [Oğuz, 2007]. When vegetable oils are fried, triglycerides are hydrolyzed by heat and water, and consequently FFA is formed [Oğuz, 2007]. Oils which are containing high FFA cause saponification during transesterification reaction [Web 2, 2019]. This makes it difficult to separate biodiesel from the glycerin and reduces the reaction yield [Web 2, 2019]. This is one of the main disadvantages of biodiesel production from waste cooking oils. Various pretreatments can be applied to waste cooking oils to reduce the FFA [Web 2, 2019]. However, these are costly and generally not wanted by the industry. Here, it must be emphasized that the biodiesel production from a waste material by itself is a win-win situation. The techno-economic benefits waste vegetable oil processing for FFA reduction is generally not feasible.

At the end of 2012, the amount of waste vegetable oil from refineries (soap stock, tank bottom residue, and fat soil) and kitchens (waste cooking oil) was close to 95 thousand tonnes [ResGaz 1, 2014]. The percent recycled of the products produced in Turkey between the years 2005 and 2009 are shown in Table 2.1 [ResGaz 1, 2014].

Table 2.1: The Percent Based on the Type of Vegetable Waste Oil Collected in Turkey (at the End of 2012) and the Percent Recycled of the Products Produced in Turkey (Between the Years 2005-2009).

The percent based on the types of vegetable waste oil collected in Turkey (at the end of 2012)		The percent recycled of the products produced in Turkey (2005-2009)	
Types of vegetable waste oil	Percent (%)	Types of recycled product	Percent (%)
Soap stock	73	Oil used in fodder	72
Fatty material (by-product or waste)	9	Industrial oil	6
Waste cooking oil	9	Soap	4
Tank bottom residue	3	Biodiesel	1
The others	6	The others	17
Total	100	Total	100

As shown in Table 2.1, biodiesel production was very low due to high Special Consumption Tax (SCT) [ResGaz 1, 2014]. During the between 2005 and 2009, 21 thousand tonnes of waste vegetable oil was collected for the purpose of producing biodiesel, but merely 1 thousand tonnes of biodiesel were produced [ResGaz 1, 2014].

According to Mustafa Öztürk, who was the undersecretary of Ministry of Environment and Urbanization of Turkey, stated that as of October 2017, 32 thousand tonnes of waste vegetable oil has been collected throughout Turkey [Web 3, 2017]. The amount of waste vegetable oil collected in 2016 was nearly 28 thousand tonnes. This clearly shows increased nationwide awareness about waste vegetable oil collection in a period of 1 year (2016 to 2017). There are waste oil bins which are available at 30 thousand points, including mosques, schools, public housing sites and etc. [Web 3, 2017]. In addition, Turkey has licensed eight biodiesel plants in general [Web 3, 2017].

On the other hand, the use of recycled waste vegetable oils in the food sector and animal feed production is prohibited (banned, not allowed) by Turkey's Ministry of Agriculture [Çanakçı, 2011]. The use in the cosmetics industry is also prohibited (banned, not allowed) by Turkey's Ministry of Health [Çanakçı, 2011]. As a result, waste vegetable oils are destined to use for biodiesel production if any capital return is wanted [Çanakçı, 2011]. There are innovative solutions for waste vegetable oil collection both in Turkey and around the globe. One such example is from Austria, where 3 liter collection buckets are placed in houses and containers with a capacity of up to 1,000 liters are placed in restaurants and special waste facilities in order to collect waste vegetable oils, and the biodiesel produced from these collected waste vegetable oils were used in municipal buses [Çanakçı, 2011]. Thus, creating a win-win situation for local residents.

3. DECISION SUPPORT TOOL AND SCENARIO DEVELOPMENT

3.1. Decision Support Tool

Decision Support Tool (DST) can be described as interactive systems (paper based or computerized) that enable identifying, solving and deciding problems using data, documents, information and communication technologies and/or models [Web 4, 2018]. It simply helps policy planners and researchers design their prospective research projects in a scientific manner [Güvel, 2007]. The aim of a DST is to create a support service for researchers/analysts/managers to make decisions about scenario analysis [Güvel, 2007]. The initial step of a DST is formulation of the problem [Güvel, 2007]. The problem must be identified by decision makers or experts from the observations and facts obtained [Güvel, 2007].

The scientific approach for decision making (generally managerial level) is explained as follows [Topçu, 2007]:

i) Identifying the problem: Purpose(s) and find the formulation of the system components that constitute the problem.

ii) Investigation of the system: Data collection for determining parameter values affecting the problem.

iii) Design of the mathematical model: Transferring the problem to an appropriate structure as ideally.

iv) Verification of the model: Does the model reflect the reality?

v) Finding and evaluating possible options: Using a solution method on a model.

vi) Choosing an appropriate option: Finding the option that best meets the objectives.

vii) Presentation of results to the decision maker: Presenting the proposal (s) resulting from the solution of the model.

In this thesis study, the aim is to generate a DST for biodiesel production from waste cooking oils. When applied properly a DST helps decision makers to design their systems in a more robust way. DSTs help efficient use of data and models and contribute to the solution of problems.

As a part of this thesis study, a proposed national biodiesel policy and strategy formulation decision tree is given in Figure 3.1 [FAO and UNEP, 2010]. Here, it must be emphasized that Figure 3.1 is a general decision tree about biodiesel policies and it can be implemented to any nation [FAO and UNEP, 2010].

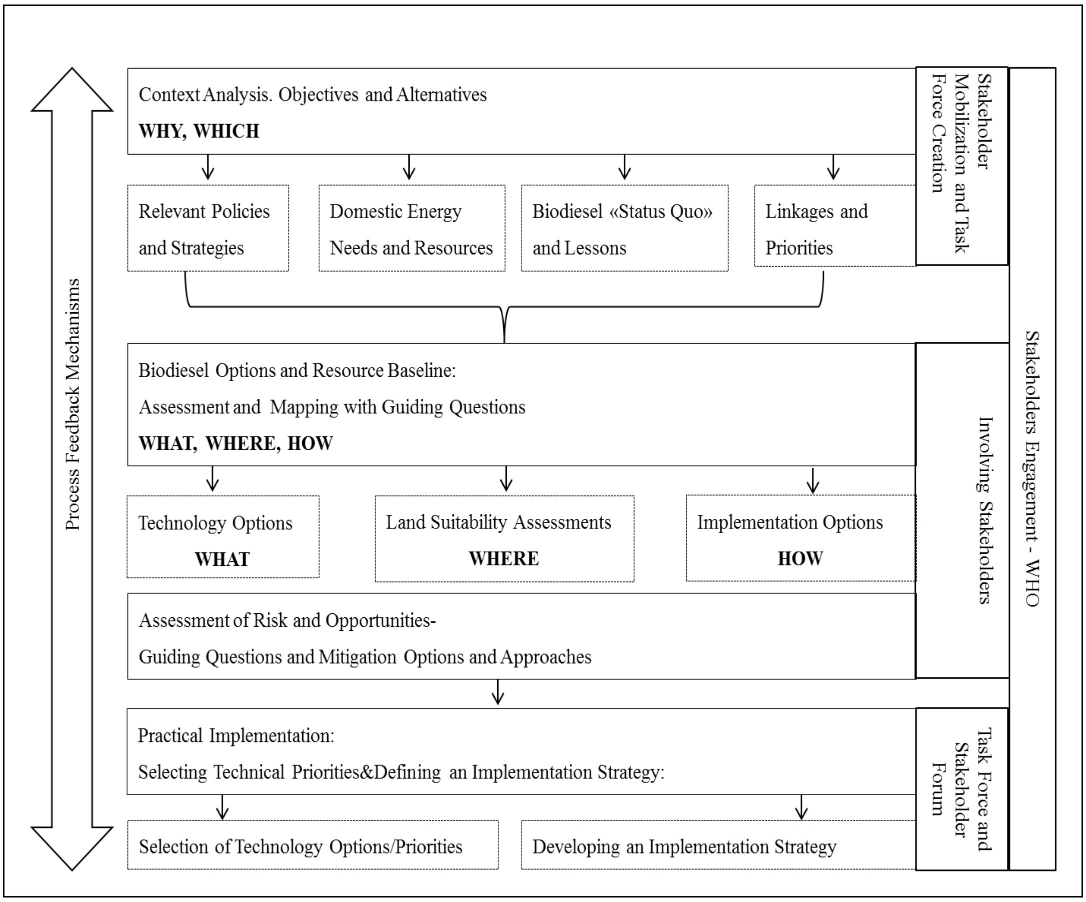

Figure 3.1: Proposed national biodiesel policy and strategy formulation decision tree.

3.1.1. Assessing Specific Development and Investment Proposals

The next step in a DST is assessing specific development and investment proposals. Details of this are explained below (as a clarification the definitions of steps are specific; as a result, they cannot be paraphrased and consequently given in quotations with proper references in the following list) [FAO and UNEP, 2010]:

i) Define the project proposal: The process must start with a clear definition of the proposal.

ii) Screening for high risk areas: The proposal should be screened to make sure it does not involve unsustainable bioenergy development on high risk areas without appropriate mitigation measures being available.

iii) Stakeholder identification: Key stakeholder groups should be identified and engaged with.

iv) Assessing potential project impacts: After the initial screening, a more detailed assessment of risks and opportunities should be carried out.

v) Assessing risk mitigation options: Appropriate risk mitigation options should be identified.

vi) Financial viability: Financial viability of the project is addressed, taking into consideration additional costs related to mitigation.

vii) Final stakeholder review: Make sure that stakeholder concerns have been addressed.

Another DST step is creating an investment level decision tree as shown in Figure 3.2 [FAO and UNEP, 2010]. In order to move in a proposed project all the logical steps in Figure 3.2 have the appropriate answers. At any step if the answer is not the same as the one in Figure 3.2 the system should be designed again. In other words, a hierarchical order must be followed to reach the final “APPROVAL”.

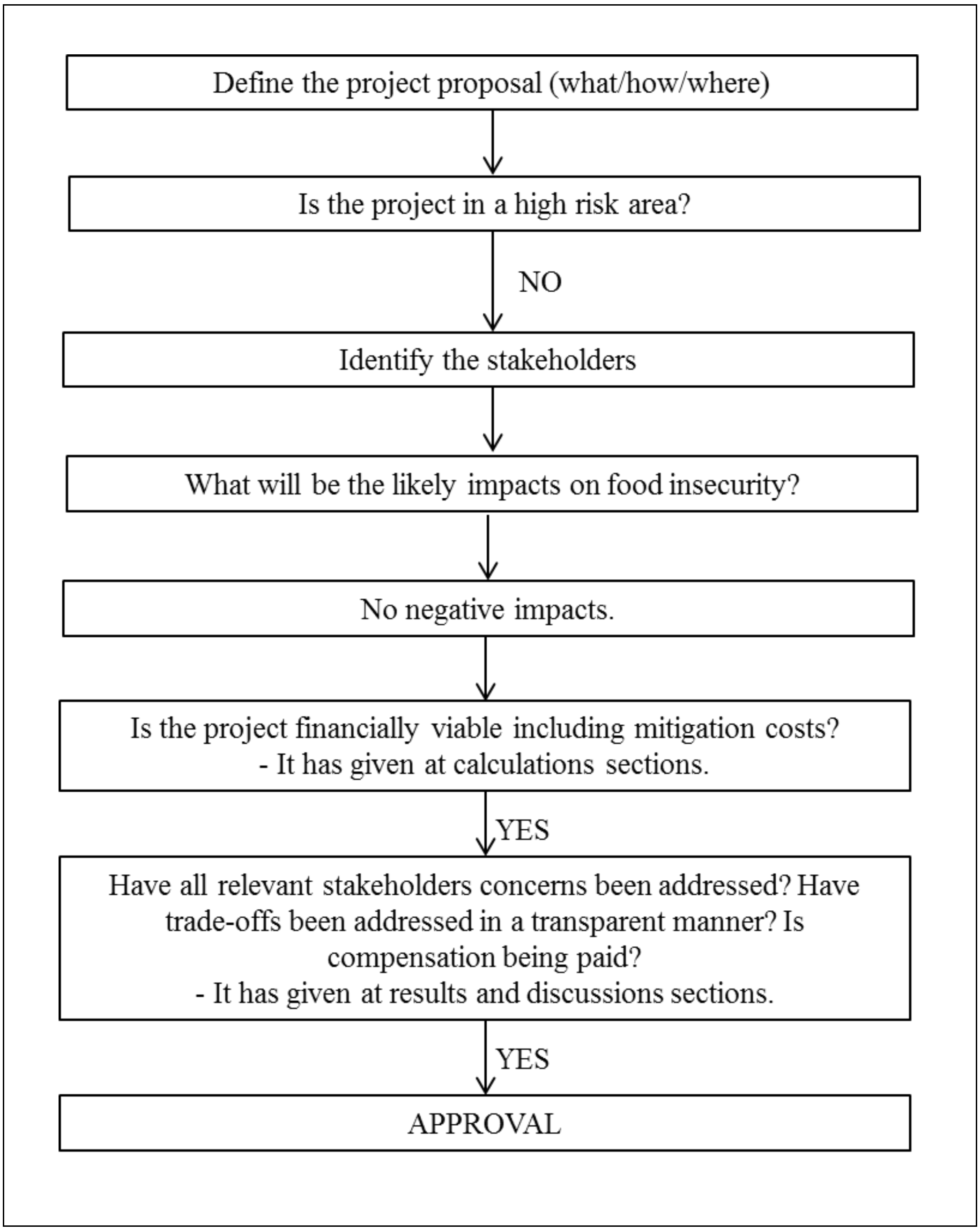

Figure 3.2: Investment level decision tree.

Opportunities in biodiesel projects are shown in Table 3.1 based on key decision making criteria modified from [FAO and UNEP, 2010]. As can be seen from Table 3.1, water and climate change opportunities are the most crucial for local and national level studies.

Table 3.1: Key Decision Making Criteria.

Opportunities in biodiesel projects.		
SCALE	WATER OPPORTUNITIES	CLIMATE CHANGE OPPORTUNITIES
NATIONAL PROVINCIAL/ STATE	• National water systems are protected and maintained	• Stabilize/reduce national GHG (Green House Gas) emissions.
LOCAL GOVERNMENT TERTIARY CATCHMENT COMMUNITY HOUSEHOLD	• Local water resources are protected and maintained	• Access and use Clean Development Mechanism (CDM) funds for projects • Reduction of traditional biomass use

Environment and natural resources: potential impacts to ecosystems, biodiversity, water, forest resources and products, soil, GHG balances, and air quality [FAO and UNEP, 2010]. Some key guiding questions to assist in assessing impacts are (as a clarification the definitions of steps are specific; as a result, they cannot be paraphrased and consequently given in quotations with proper references in the following list) [FAO and UNEP, 2010]:

- Will bioenergy production directly affect any rare or threatened ecosystems or habitat types through conversion, habitat loss or fragmentation?
- Will bioenergy production lead to a reduction in soil productivity?
- Will bioenergy production result in the introduction of non-endemic invasive species?
- To what extent will bioenergy production adversely impact water availability and/or quality both for downstream ecosystem processes and services and for downstream human activities and domestic uses (both current and projected)?
- Will the GHG balance be positive or negative compared to traditional fuels?

In this thesis study, the bioenergy concept given in the above list is changed to biodiesel and solutions regarding to it are conceptualized as follows [FAO and UNEP, 2010]:

- Will biodiesel production directly affect any rare or threatened ecosystems or habitat types through conversion, habitat loss or fragmentation? Answer: NO.
- Will biodiesel production lead to a reduction in soil productivity Answer: NO.
- Will biodiesel production result in the introduction of non-endemic invasive species? Answer: NO.
- To what extent will biodiesel production adversely impact water availability and/or quality both for downstream ecosystem processes and services and for downstream human activities and domestic uses (both current and projected)? Answer: NO adverse effects instead favorable for water resources.
- Will the GHG balance be positive or negative compared to traditional fuels? Answer: GHGs will be reduced.

As can be seen from the above DST step biodiesel production in Turkey from waste vegetable oils have significantly environmental benefits (water-GHG-species nexus).

3.1.2. Defining an Implementation Strategy

Four key areas for policy implementation in a DST is explained in Table 3.2 [FAO and UNEP, 2010].

Table 3.2: Four Key Areas for Policy Implementation.

Technology	Market/Fiscal support	Regulation	Institutions
Which technology will be preferred under what circumstances?	To which market is the product destined?	What instruments will be used to regulate? • Licensing • Certification • Mandates	What institution will house and implement the policy?
How will technology choice be supported? • Grants, research, micro credit schemes, reduced import tariffs, etc.	What support is required to ensure it reaches its intended markets? • Infrastructure, trade agreements, certification, import restrictions, etc. • Incentives Grants, taxes, subsidies, fuel charges, etc.	How to use regulation to support certain activities • Supporting certain activities with grants.	What additional capacity is needed in the country to implement • Skilled biofuels experts, extension officers, regulatory bodies, etc.

In this thesis study, it is suggested that the four key areas for policy implementation given in Table 3.2 should be answered by the action takers (either government or private sector) if biodiesel production from waste vegetable oils is wanted [FAO and UNEP, 2010]. Details of this are explained in Table 3.3 [FAO and UNEP, 2010].

Table 3.3: Four key areas for policy implementation for biodiesel production from waste vegetable oils.

Technology	Market/ Fiscal Support	Regulation	Institutions
Which technology will be preferred under what circumstances? Answer: Conventional biodiesel production from waste vegetable oils	To which market is the product destined? Answer: Energy market	What instruments will be used to regulate? • Licensing • Certification • Mandates Answer: All above	What institution will house and implement the policy? Answer: Municipalities and the Ministry of Environment and Urbanization
How will technology choice be supported? • Grants, research, micro credit schemes, reduced import tariffs, etc. Answer: Decision will be made by authorities	What support is required to ensure it reaches its intended markets? • Infrastructure, trade agreements, certification, import restrictions, etc. • Incentives Grants, taxes, subsidies, fuel charges, etc. Answer: All above	How to use regulation to support certain activities • Supporting certain activities with grants Answer: Incentives and trade-offs based on the decision of authorities	What additional capacity is needed in the country to implement • Skilled biofuels experts, extension officers, regulatory bodies, etc. Answer: All above

Based on the answers given to the lists, tables and figures above specific to this thesis study, the decision tree given in Figure 3.1 is modified for Turkey based on the above parameters and shown in Figure 3.3 based on [FAO and UNEP, 2010].

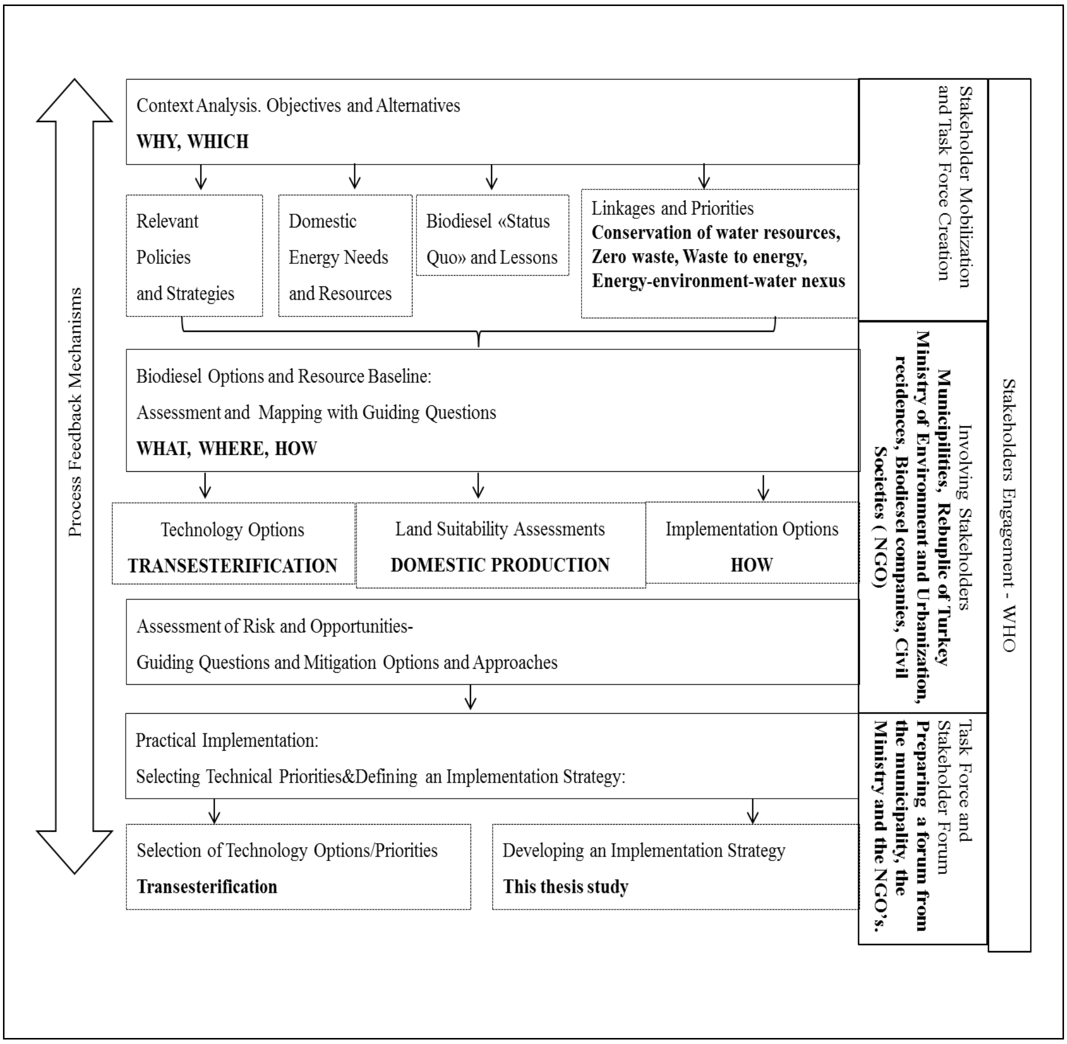

Figure 3.3: Proposed national bioenergy policy and strategy formulation decision tree for Turkey.

Example of statements of implementation priorities is as given below; Water: Water conserving practices will be promoted for biodiesel [FAO and UNEP, 2010]. As a result, water pollution related calculations associated with waste cooking oil reutilization is given in section 4.

3.2. Sustainability Scenarios

Sustainability is the long-term reproduction of a system to sustain itself [Web 5, 2014]. Sustainability is a key concept for reducing global carbon emissions, protecting environment, keeping the ecosystems of our planet in balance via driving innovation [Web 6, 2019].

The main objectives of sustainability are explained in Figure 3.4 [Web 6, 2019]:

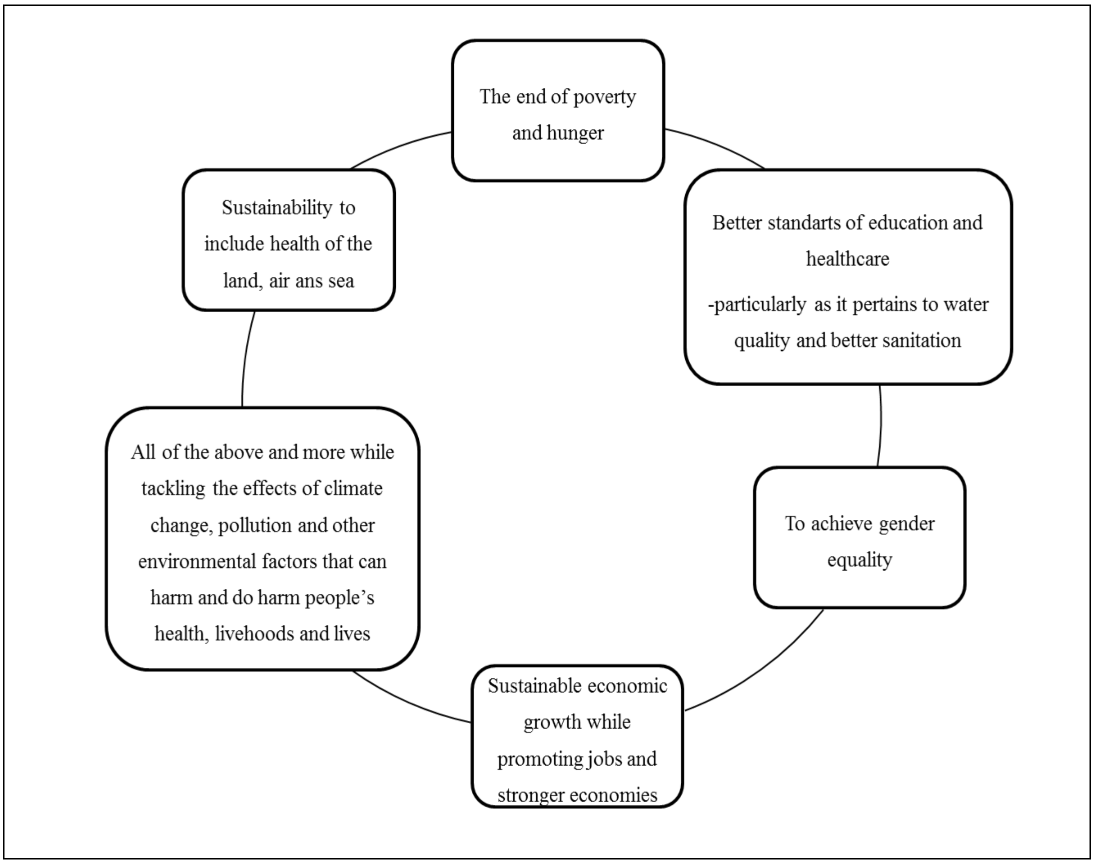

Figure 3.4: The main objectives of sustainability.

A sustainability scenario can be defined as a projection for the future in which the suggested policy follows an integrated approach to economic, social and environmental goals, and suggests institutional changes, with the overall goal of development that "meets the needs of the present without compromising the ability of future" [Web 6, 2019].

More simply, the concept of sustainability is a participatory process, which creates a social outlook that ensures that the cultural, human, natural scientific, and social resources of a society are moderately used with a purpose [Lale, 2016]. There are some requirements for sustainability [Lale, 2016]:

i) A political system in which citizens can play an active role in decision making.

ii) To find solutions to problems arising from incompatible development social system.

iii) A technological system that can continuously search for new solutions."

iv) A production system that respects protecting the necessary ecological base for development.

v) It is an economic system capable of providing production surplus and technical information in a sustainable manner at its own expense.

What should be done for ecological sustainability is defined as follows: First of all, with the use of high technology as a business, firms support energy consumption if they start to produce more efficient products through innovative approach and environmentally friendly solutions [Yeniyıldız, 2016]. Secondly, energy production such as natural gas, wind, geothermal, bio-fuel, small hydro, waste heat evaluation and electricity generation from waste should be ensured [Yeniyıldız, 2016]. In addition, turning the use of energy into a need for awareness plays an important role [Yeniyıldız, 2016].

In this thesis study, the suggested sustainability scenario aims is to provide a novel and valuable way for reutilization of waste cooking oils for biodiesel production. Thus reducing the environmental impacts associated with this imported problems.

4. RESULTS AND DISCUSSION

4.1. Methodology for Forecasting Turkey's Waste Sunflower Oil Generation and Associated Potential Biodiesel Generation Between 2017 and 2030

Turkey's waste sunflower oil generation between 2017 and 2030 are estimated based on the following methodology. First, Turkey's sunflower oil consumption between 2010 and 2017 is found from Turkey's Ministry of Customs and Trade (MCT) and shown in Table 4.1 [MCT, 2018], [TUIK 1, 2018]. In addition, Turkey's sunflower oil production between 2010 and 2016 is found from the literature and shown in Table 4.2 [TUIK 3, 2019].

Table 4.1: Turkey's Sunflower Oil Consumption Between 2010 And 2018.

Year	Sunflower oil consumption (thousand tonnes)	Sunflower oil consumption per capita (kg)
2010	726	9.8
2011	846	11.3
2012	825	10.9
2013	870	11.3
2014	827	10.6
2015	876	11.1
2016	1,032	12.9
2017	1,061	13.1

Table 4.2: Sunflower Oil Production in Turkey Between 2010 And 2016.

Year	Crude sunflower oil (thousand tonnes)
2010	528.6
2011	668.1
2012	547.2
2013	698.0
2014	721.9
2015	816.9
2016	731.1

As can be seen from Tables 4.1 and 4.2, Turkey's annual sunflower oil consumption is significantly greater than Turkey's annual sunflower oil production. This means that the gap in between is supplied from sunflower oil imports. In this thesis study, sunflower oil consumption data is used for the associated calculations. As can be seen from Table 4.1, Turkey's sunflower oil consumption increased from 726,000 tonnes to 1,061,000 tonnes between 2010 and 2017. This means an annual growth rate of 5.6% in sunflower oil consumption between 2010 and 2017. This is significantly higher than Turkey's annual population growth rate in the same period. As a result, Turkish people's per capita sunflower oil consumption in the same period must have increased. In order to validate this, Turkey's population data between 2010 and 2017 is found from the literature and shown in Table 4.3 [TUIK 1, 2018] and Turkey's per capita sunflower oil consumption between 2010 and 2017 is calculated and shown in Table 4.1.

Table 4.3: Turkey's Population between 2010 and 2017.

Year	Population
2010	73,722,988
2011	74,724,269
2012	75,627,384
2013	76,667,864
2014	77,695,904
2015	78,741,053
2016	79,814,871
2017	80,810,525

Turkey's sunflower oil consumption between 2017 and 2030 can be estimated using Equation (4.1).

$$SO_c(t) = SO_{cpc}(t) \times P(t) + \varepsilon \tag{4.1}$$

In Equation (4.1), t is year, which is ≥ 2018, $SO_c(t)$ is sunflower oil consumption at year t in tonnes, $SO_{cpc}(t)$ is sunflower oil consumption per capita at year t in kg, $P(t)$ is population at year t in number of people, and ε is a "random" error term. In order to calculate Turkey's sunflower oil consumption between 2018 and 2030 first, $SO_{cpc}(t)$ and $P(t)$ data must be found from the literature or calculated. Systematically the following solution is applied to this problem. First, Turkey's population projection between 2018 and 2030 is found from TUIK and shown in Table 4.4 [TUIK 2, 2018]. Then, Turkey's $SO_{cpc}(t)$ data must be found or calculated/estimated from the literature. Details of this methodology are explained in the next paragraph.

Table 4.4: Turkey's Population Projection Between 2018 And 2030.

Year	Population
2018	81,867,223
2019	82,886,421
2020	83,900,373
2021	84,908,658
2022	85,911,035
2023	86,907,367
2024	87,885,571
2025	88,844,934
2026	89,784,584
2027	90,703,600
2028	91,601,117
2029	92,476,323
2030	93,328,574

A detailed literature review was carried out to find $SO_{cpc}(t)$ projections but data for Turkey cannot be found from the literature. However, it was found that in most emerging markets, the per capita level of vegetable oil food availability is set to reach levels comparable to those of developed countries. According to the Organization for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization of the United Nations (FAO) joint OECD-FAO Agricultural Outlook 2018-2027 report vegetable oil consumption in emerging economies will stabilize around 27.7 kg per capita [OECD-FAO, 2018]. As can be seen from Table 4.1, Turkey's sunflower oil consumption per capita increased from 9.8 kg to 13.1 kg between 2010 and 2017. This is equal to an increase of nearly 4.0% (exactly 4.2%) in per capita sunflower oil consumption between 2010 and 2017. According to the OECD-FAO Agricultural Outlook 2018-2027 report in developing economies vegetable oil consumption per capita increased nearly 2.8% p.a. (per annum) between 2008 and 2017. This shows that Turkey's sunflower oil consumption per capita is slightly higher than the developing economies average.

In this study, it is assumed that Turkey's annual per capita sunflower oil consumption between 2017 and 2030 can increase 2.0%, 4.0% or 6.0% between 2018 and 2030. These values are selected to provide data for low demand growth, high demand growth and business as usual (BAU) scenarios. The value 2.0% is used to project a scenario where Turkey's annual sunflower oil consumption turns out to be much smaller than Turkey's average demand growth between 2010 and 2017 (50% smaller: 4.0%×50%=2.0%). Then, the value 4.0% is used to project a BAU scenario, which follows Turkey's average demand growth between 2010 and 2017. Finally, the value 6.0% is used to project a scenario where Turkey's annul sunflower oil consumption turns out to be much higher than Turkey's average demand growth between 2010 and 2017 (50% greater: 4.0%×1.50%=6.0%). As a result, $SO_{cpc}(t)$ values are assumed to rise 2.0%, 4.0%, and 6.0% between 2017 and 2030. Based on the explanations and data given above and using Equation (4.1) Turkey's annual sunflower oil consumption between 2018 and 2030 are calculated and shown in Table 4.5.

Table 4.5: Turkey's Sunflower Oil Consumption Projections Between 2018 and 2030.

Years	Sunflower oil consumption per capita, kg (2.0% annual increase between 2018 and 2030)	Sunflower oil consumption per capita (4.0% annual increase between 2018 and 2030)	Sunflower oil consumption per capita (6.0% annual increase between 2018 and 2030)	Sunflower oil consumption, thousand tonnes (based on 2.0% annual increase in per capita consumption between 2018 and 2030)	Sunflower oil consumption, thousand tonnes (based on 4.0% annual increase in per capita consumption between 2018 and 2030)	Sunflower oil consumption, thousand tonnes (based on 6.0 % annual increase in per capita consumption between 2018 and 2030)
2010	9.8	9.8	9.8	726.0	726.0	726.0
2011	11.3	11.3	11.3	846.0	846.0	846.0

Table 4.5: “Continue”

2012	10.9	10.9	10.9	825.0	825.0	825.0
2013	11.3	11.3	11.3	870.0	870.0	870.0
2014	10.6	10.6	10.6	827.0	827.0	827.0
2015	11.1	11.1	11.1	876.0	876.0	876.0
2016	12.9	12.9	12.9	1032.0	1032.0	1032.0
2017	13.1	13.1	13.1	1061.0	1061.0	1061.0
2018	13.4	13.7	13.9	1096.4	1117.9	1139.4
2019	13.7	14.2	14.8	1132.2	1177.1	1222.8
2020	13.9	14.8	15.6	1169.0	1239.1	1312.0
2021	14.2	15.4	16.6	1206.7	1304.2	1407.4
2022	14.5	16.0	17.6	1245.4	1372.3	1509.5
2023	14.8	16.6	18.6	1285.0	1443.8	1618.6
2024	15.1	17.3	19.7	1325.5	1518.4	1735.0
2025	15.4	18.0	20.9	1366.7	1596.4	1859.2
2026	15.7	18.7	22.2	1408.8	1677.8	1991.6
2027	16.0	19.4	23.5	1451.7	1762.8	2132.7
2028	16.3	20.2	24.9	1495.4	1851.5	2283.0
2029	16.7	21.0	26.4	1539.9	1943.9	2443.1
2030	17.0	21.9	28.0	1585.1	2040.3	2613.6

Note: Data between 2010 and 2017 was taken from Table 4.1.

The aim of this study is to calculate biodiesel production potentials from wasted sunflower oils in Turkey. Therefore, the amount of sunflower oil that will be wasted between 2018 and 2030 must be estimated. This can be done using Equation (4.2).

$$SO_{wt}(t) = SO_c(t) \times [WF_c(t) + WF_d(t) + WF_p(t) + WF_{ph}(t) + WF_a(t)] + \varepsilon \qquad (4.2)$$

In Equation (4.2), t is year which is ≥ 2018, $SO_c(t)$ is explained in Equation (4.1), $SO_{wt}(t)$ is the total amount of sunflower oil waste generated at year t in tonnes, $WF_c(t)$ is sunflower oil waste fraction for consumption at year t in %, $WF_d(t)$ is sunflower oil waste fraction for distribution at year t in %, $WF_p(t)$ is sunflower oil waste fraction for processing at year t in %, $WF_{ph}(t)$ is sunflower oil waste fraction for postharvest at year t in %, $WF_a(t)$ is sunflower oil waste fraction for agriculture at year t in %, and ε is a "random" error term.

In order to calculate $SO_{wt}(t)$ first $WF_c(t)$, $WF_d(t)$, $WF_p(t)$, $WF_{ph}(t)$, and $WF_a(t)$ values must be found from the literature. Consequently, after a detailed literature review, part of the initial production lost or wasted at different stages in the food supply chains (FSC) for oilseeds and pulses in different regions for oil seed is found from the Food and Agriculture Organization of the United Nations (FAO) report. Due to Turkey's unique geographical location data for average of data for Europe, North Africa, West and Central Asia is used for the loss of oil seeds [FAO, 2011]. Part of the initial production lost or wasted at different food supply chain (FSC) stages, %, for oilseeds in different regions of the world is shown in Table 4.6 [FAO, 2011].

Table 4.6: Part of the Initial Production Lost or Wasted at Different Food Supply Chain (FSC) Stages, Percent Oilseeds in Different Regions of the World.

	Consumption	Distribution	Processing	Post-harvest	Agriculture	Total[1]	Region
Oilseeds[1]	4%	1%	5%	1%	10%	20%	Europe
Oilseeds[2]	4%	1%	5%	1%	10%	N/A	Europe
Oilseeds[1]	2%	2%	6%	4%	16%	29%	North Africa, West and Central Asia
Oilseeds[2]	2%	2%	8%	6%	15%	N/A	North Africa, West and Central Asia
Average	3%	1.5%	6%	3%	12.8%	24.5%	Estimated for Turkey due to unique geographical location

Notes:
[1] Values given in this table are approximate values read from Figure 5 in the source publication (FAO, 2011). Total values are not given in the Annex 4 of the source publication but only in the Figure 5 of (FAO, 2011).
[2] Data taken from Annex 4 of the source publication (FAO, 2011). Values are assumed/estimated waste percentages of each commodity group in each step of the food supply chain (FAO, 2011).
Both values are given because some of the data shown in Figure 5 of the source publication is slightly different than the one's given in the Annex 4 (FAO, 2011).

As can be seen from Table 4.6, during consumption, distribution, processing, post-harvest, and agriculture of oilseeds on average nearly 3.0%, 1.5%, 6.0%, 3.0%, and 12.8% of the initial production can be wasted or lost in Turkey, respectively. Using the average values given in Table 4.6 and sunflower oil consumption projections given in Table 4.5, Turkey's sunflower oil waste generation values related to consumption are calculated and shown in Tables 4.7-4.9. Three tables are created because three data sets were created for Turkey's sunflower oil consumption projections (2.0%, 4.0%, and 6.0% annual increase in per capita sunflower oil consumption). As a clarification, the total columns generated in Tables 4.7- 4.9 are calculated using Equation (4.3), which only includes consumption + distribution + processing terms of Table 4.6 because all data used in these calculations, starting from Table 4.1 are for sunflower consumption and this does not include agriculture + post-harvest values.

$$SO_{wtc}(t) = SO_c(t) \times [WF_c(t) + WF_d(t) + WF_p(t)] + \varepsilon \quad (4.3)$$

In Equation (4.3), $SO_{wtc}(t)$ is the total amount of sunflower oil waste generated from consumption routes at year t in tonnes.

Table 4.7: Part of the Initial Production Lost or Wasted at Different Food Supply Chain (FSC) Stages, Percent Sunflower Oil Consumption in Turkey Based on Average Data in Thousand Tonnes and 2.0% Increase in Sunflower Oil Consumption Per Capita.

	Sunflower oil waste in thousand tonnes			
Years	Consumption (3%)	Distribution (1.5%)	Processing (6%)	Total (consumption + distribution + processing)
2010	21.8	10.9	43.6	76.2
2011	25.4	12.7	50.8	88.8
2012	24.8	12.4	49.5	86.6
2013	26.1	13.1	52.2	91.4
2014	24.8	12.4	49.6	86.8
2015	26.3	13.1	52.6	92.0
2016	31.0	15.5	61.9	108.4
2017	31.8	15.9	63.7	111.4
2018	32.9	16.4	65.8	115.1
2019	34.0	17.0	67.9	118.9
2020	35.1	17.5	70.1	122.7

Table 4.7: “Continued”

2021	36.2	18.1	72.4	126.7
2022	37.4	18.7	74.7	130.8
2023	38.6	19.3	77.1	134.9
2024	39.8	19.9	79.5	139.2
2025	41.0	20.5	82.0	143.5
2026	42.3	21.1	84.5	147.9
2027	43.6	21.8	87.1	152.4
2028	44.9	22.4	89.7	157.0
2029	46.2	23.1	92.4	161.7
2030	47.6	23.8	95.1	166.4

Table 4.8: Part of the Initial Production Lost or Wasted at Different Food Supply Chain (FSC) Stages, Percent Sunflower Oil Consumption in Turkey Based on Average Data in Thousand Tonnes and 4.0% Increase in Sunflower Oil Consumption Per Capita.

	Sunflower oil waste in thousand tonnes			
Years	Consumption (3%)	Distribution (1.5%)	Processing (6%)	Total (consumption + distribution + processing)
2010	21.8	10.9	43.6	76.2
2011	25.4	12.7	50.8	88.8
2012	24.8	12.4	49.5	86.6
2013	26.1	13.1	52.2	91.4
2014	24.8	12.4	49.6	86.8
2015	26.3	13.1	52.6	92.0
2016	31.0	15.5	61.9	108.4
2017	31.8	15.9	63.7	111.4
2018	33.5	16.8	67.1	117.4
2019	35.3	17.7	70.6	123.6
2020	37.2	18.6	74.3	130.1
2021	39.1	19.6	78.2	136.9
2022	41.2	20.6	82.3	144.1
2023	43.3	21.7	86.6	151.6

Table 4.8: “Continued”

2024	45.6	22.8	91.1	159.4
2025	47.9	23.9	95.8	167.6
2026	50.3	25.2	100.7	176.2
2027	52.9	26.4	105.8	185.1
2028	55.5	27.8	111.1	194.4
2029	58.3	29.2	116.6	204.1
2030	61.2	30.6	122.4	214.2

Table 4.9: Part of the Initial Production Lost or Wasted at Different Food Supply Chain (FSC) Stages, Percent Sunflower Oil Consumption in Turkey Based on Average Data in Thousand Tonnes and 6.0% Increase in Sunflower Oil Consumption Per Capita.

	Sunflower oil waste in thousand tonnes			
Years	Consumption (3%)	Distribution (1.5%)	Processing (6%)	Total (consumption + distribution + processing)
2010	21.8	10.9	43.6	76.2
2011	25.4	12.7	50.8	88.8
2012	24.8	12.4	49.5	86.6
2013	26.1	13.1	52.2	91.4
2014	24.8	12.4	49.6	86.8
2015	26.3	13.1	52.6	92.0
2016	31.0	15.5	61.9	108.4
2017	31.8	15.9	63.7	111.4
2018	34.2	17.1	68.4	119.6
2019	36.7	18.3	73.4	128.4
2020	39.4	19.7	78.7	137.8
2021	42.2	21.1	84.4	147.8
2022	45.3	22.6	90.6	158.5
2023	48.6	24.3	97.1	170.0
2024	52.1	26.0	104.1	182.2
2025	55.8	27.9	111.6	195.2
2026	59.7	29.9	119.5	209.1
2027	64.0	32.0	128.0	223.9
2028	68.5	34.2	137.0	239.7
2029	73.3	36.6	146.6	256.5
2030	78.4	39.2	156.8	274.4

When the consumption loss (waste) forecasts are available, then estimation of potential biodiesel yield can be carried out using Equation (4.4).

$$B_{yfcl}(t) = SO_{wtc}(\mathrm{t}) \times B_{yoc} / \rho_b \times A + \varepsilon \quad (4.4)$$

In Equation (4.4), t is year which is ≥2018, $SO_{wtc}(t)$ is explained in Equation (4.3) and it's values between 2018 and 2030 are given in Tables 4.7-4.9, $B_{yfcl}(t)$ is biodiesel yield from sunflower oil consumption losses in year t in litres, B_{yoc} is biodiesel yield in kg per kg of waste sunflower oil, ρ_b is biodiesel density, which is assumed as 0.8747×10^3 kg/m^3 [Yıldız, 2008], and A is the availability factor of sunflower oil consumption losses, which is the amount that can be recovered to produce biodiesel in %, and ε is a "random" error term. In this study, A is assumed as 100% or 1.0 in order to calculate maximum biodiesel production potentials from sunflower oil loss/waste streams and B_{yoc} is assumed as 1.0 based on the stoichiometric (weight %) equation given in Figure 2.1. The results are shown in Table 4.10.

Table 4.10: Biodiesel Production from Sunflower Oil Consumption Loss/Waste Streams Given in Tables 4.6 Through 4.9 in Million Litres.

	Biodiesel (million litres)		
Years	based on 2.0% annual increase in per capita sunflower oil consumption	based on 4.0% annual increase in per capita sunflower oil consumption	based on 6.0% annual increase in per capita sunflower oil consumption
2018	131.6	134.2	136.8
2019	135.9	141.3	146.8
2020	140.3	148.7	157.5
2021	144.9	156.6	168.9
2022	149.5	164.7	181.2
2023	154.3	173.3	194.3
2024	159.1	182.3	208.3
2025	164.1	191.6	223.2
2026	169.1	201.4	239.1
2027	174.3	211.6	256.0
2028	179.5	222.3	274.1

Table 4.10: “Continued”

2029	184.8	233.4	293.3
2030	190.3	244.9	313.7

As can be seen from Table 4.10, nearly between 190 and 310 million litres of biodiesel can be produced from Turkey's sunflower oil wastes in 2030. This amount is really significant. A cost balance can be made on current diesel prices on the economic return potential of waste sunflower oil based biodiesel using Equation (4.5).

$$NW_{b2018}(t) = B_{yfcl}\ (\mathrm{t}) \times \frac{EC_b}{EC_d} \times P_d(t) + \varepsilon \tag{4.5}$$

In Equation (4.5), $NW_{b2018}(t)$ is net value of biodiesel in TL in year t based on average diesel price at the end of 2018; $P_d(2018)$, $B_{yfcl}(t)$ is explained in Equation (4.4), EC_d is energy content of diesel in MJ/L, which is assumed as 35.8 MJ/L [Harahap et al., 2019], EC_b is energy content of biodiesel in MJ/L, which is assumed as 33.0 MJ/L [Harahap et al., 2019], $P_d(t)$ is average price of diesel in TL in year (t), and ε is a "random" error term. The price of diesel in Turkey fluctuates very often and long-term price forecasting (between 2018 and 2030) is almost impossible. As a result, in this study, $P_d(t)$ is taken as a constant value for the calculations as 6.00 TL and NW_{b2018} is estimated as net value of biodiesel based on diesel prices in 2018. The results are shown in Table 4.11-4.13.

Table 4.11: Biodiesel Production Potentials from Turkey’s Sunflower Oil Consumption Wastes, Based on 2.0% Annual Increase in Per Capita Consumption.

Year	Biodiesel production potential (kg)[1]	Diesel equivalent of biodiesel (litres)	Diesel net value (TL)	Biodiesel production potential (million litres)
2018	115,118,994	121,316,193	727,897,156	131.6
2019	118,883,200	125,283,037	751,698,222	135.9
2020	122,744,251	129,351,941	776,111,643	140.3

Table 4.11: "Continued"

2021	126,703,735	133,524,575	801,147,452	144.9
2022	130,763,509	137,802,898	826,817,389	149.5
2023	134,925,606	142,189,054	853,134,323	154.3
2024	139,173,175	146,665,282	879,991,694	159.1
2025	143,506,244	151,231,613	907,389,679	164.1
2026	147,924,488	155,887,705	935,326,227	169.1
2027	152,427,384	160,633,005	963,798,029	174.3
2028	157,014,375	165,466,927	992,801,560	179.5
2029	161,684,865	170,388,844	1,022,333,062	184.8
2030	166,438,433	175,398,310	1,052,389,860	190.3

[1] It is assumed that 1 kg biodiesel can be produced from 1 kg of waste vegetable oil.

Table 4.12: Biodiesel Production Potentials from Turkey's Sunflower Oil Consumption Wastes, Based on 4.0% Annual Increase in Per Capita Consumption.

Year	Biodiesel production potential (kg)[1]	Diesel equivalent of biodiesel (litres)	Diesel net value (TL)	Biodiesel production potential (million litres)
2018	117,376,229	123,694,942	742,169,649	134.2
2019	123,590,993	130,244,264	781,465,587	141.3
2020	130,107,000	137,111,048	822,666,289	148.7
2021	136,937,403	144,309,152	865,854,914	156.6
2022	144,096,158	151,853,284	911,119,705	164.7
2023	151,597,969	159,758,940	958,553,639	173.3
2024	159,436,484	168,019,425	1,008,116,553	182.3
2025	167,623,976	176,647,675	1,059,886,048	191.6
2026	176,172,689	185,656,590	1,113,939,541	201.4
2027	185,094,994	195,059,209	1,170,355,254	211.6
2028	194,403,579	204,868,904	1,229,213,422	222.3
2029	204,111,455	215,099,384	1,290,596,303	233.4
2030	214,232,224	225,764,983	1,354,589,899	244.9

[1] It is assumed that 1 kg biodiesel can be produced from 1 kg of waste vegetable oil.

Table 4.13: Biodiesel Production Potentials from Turkey's Sunflower Oil Consumption Wastes, Based on 6.0% Annual Increase in Per Capita Consumption.

Year	Biodiesel production potential (kg)[1]	Diesel equivalent of biodiesel (litres)	Diesel net value (TL)	Biodiesel production potential (million litres)
2018	119,633,464	126,073,690	756,442,143	136.8
2019	128,390,199	135,301,826	811,810,959	146.8
2020	137,758,448	145,174,396	871,046,378	157.5
2021	147,778,819	155,734,194	934,405,164	168.9
2022	158,494,805	167,027,053	1,002,162,319	181.2
2023	169,952,884	179,101,955	1,074,611,728	194.3
2024	182,177,774	191,984,946	1,151,909,679	208.3
2025	195,216,421	205,725,503	1,234,353,017	223.2
2026	209,117,952	220,375,395	1,322,252,370	239.1
2027	223,933,945	235,988,977	1,415,933,865	256.0
2028	239,718,771	252,623,547	1,515,741,283	274.1
2029	256,529,722	270,339,482	1,622,036,894	293.3
2030	274,427,503	289,200,753	1,735,204,520	313.7

[1] It is assumed that 1 kg biodiesel can be produced from 1 kg of waste vegetable oil.

Biodiesel production from sunflower oil wastes provide a chance for decreasing Turkey's water pollution associated with the discharge of sunflower oil wastes into the sewage. After a detailed literature review it was found that 1 litre of vegetable can pollute up to 25,000 liters of fresh water [Web 7, 2016]. As a result, recovery of waste sunflower oil is essential for protecting Turkey's water resources. Based on this figure water pollution potential of Turkey's sunflower oil waste generation is estimated and reported in Table 4.14.

In 2016, the total amount of water abstracted by municipalities in Turkey was nearly 5,839 million m^3 [TUIK 4, 2016]. This means that there is a huge potential for water recovery in Turkey via production of biodiesel from waste sunflower and other vegetable oils.

Table 4.14: Water Pollution Potential of Sunflower Oil Consumption Waste in Turkey between 2018 and 2030.

	Water pollution potential of sunflower oil consumption waste (million m^3)		
Year	Based on 2.0% annual increase in per capita consumption	Based on 4.0% annual increase in per capita consumption	Based on 6.0% annual increase in per capita consumption
2018	3,128	3,190	3,251
2019	3,231	3,358	3,489
2020	3,335	3,536	3,743
2021	3,443	3,721	4,016
2022	3,553	3,916	4,307
2023	3,666	4,120	4,618
2024	3,782	4,333	4,950
2025	3,900	4,555	5,305
2026	4,020	4,787	5,683
2027	4,142	5,030	6,085
2028	4,267	5,283	6,514
2029	4,394	5,547	6,971
2030	4,523	5,822	7,457

5. CONCLUSIONS

In this thesis study, it is estimated that sunflower oil consumption in Turkey will be 17.0, 21.9 and 28.0 kg per capita in 2030 based on 2.0%, 4.0% and 6.0% annual increases in per capita consumption, respectively. Sunflower oil consumption in Turkey is estimated to reach nearly 1,585, 2,040, and 2,614 thousand tonnes based on 2.0%, 4.0% and 6.0% annual increases in per capita consumption, respectively. Sunflower oil waste generation in Turkey is estimated at nearly 166.4, 214.2, and 274.4 thousand tonnes in 2030 based on 2.0%, 4.0% and 6.0% annual increases in sunflower oil consumption per capita, respectively.

Biodiesel production from sunflower oil consumption is estimated to reach nearly 190.3, 244.9, and 313.7 million litres in 2030 based on 2.0%, 4.0% and 6.0% annual increases in sunflower consumption per capita, respectively. Similarly, it is estimated that biodiesel production from Turkey's sunflower oil consumption wastes in kg and million litres, diesel equivalent of these productions in litres and their potential net in TL will be: i) 166,438,433 kg, 190.3 million litres, 175,398,310 litres, and 1,052,389,860 TL in 2030 based on 2.0% annual increase in sunflower consumption per capita, ii) 214,232,224 kg, 244.9 million litres, 225,764,983 litres, and 1,354,589,899 TL in 2030 based on 4.0% annual increase in sunflower consumption per capita, iii) 274,427,503 kg, 313.7 million litres, 289,200,753 litres, and 1,735,204,520 TL in 2030 based on 6.0% annual increase in sunflower consumption per capita, respectively.

Finally, water pollution potential of sunflower oil consumption waste in Turkey is estimated to reach 4,523, 5,822, and 7,457 million m^3 in 2030 based on 2.0%, 4.0% and 6.0% annual increases in sunflower oil consumption per capita, respectively. It is also found that these amounts are almost equal to or higher than the total amount of water abstracted by municipalities in Turkey in 2016. As a result, there is a vast potential for fresh water pollution prevention in Turkey via production of biodiesel from waste sunflower and other vegetable oils.

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