

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

**SOCIO-ECONOMIC IMPACT ANALYSIS OF AIR POLLUTION
REDUCTION SCENARIOS WITH BENMAP-CE PROGRAM:
DILOVASI EXAMPLE**



M.Sc. THESIS

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Department of Meteorological Engineering

Atmospheric Sciences Programme

OCTOBER 2021

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

**HAVA KİRLİLİĞİ AZALTMA SENARYOLARININ BENMAP-CE
PROGRAMI İLE SOSYO-EKONOMİK ETKİ ANALİZİ:
DİLOVASI ÖRNEĞİ**

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To my family and my best friend,



FOREWORD

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ABBREVIATIONS

AQI	: Air Quality Index
BenMAP-CE	: The Environmental Benefits Mapping and Analysis Program – Community Edition
CO	: Carbon Monoxide
CPI	: Consumer Price Index
EDGAR	: Emissions Database for Global Atmospheric Research
EPA	: Environmental Protection Agency
GDAS	: Global Data Assimilation Systems
GOCART	: Goddard Chemistry Aerosol Radiation and Transport Model
HIF	: Health Impact Function
ITS	: Intelligent Transportation System
MOD	: WRF-Chem Model Output Air Pollution Data
MoEU	: Ministry of Environment and Urbanization
NCAR	: National Center for Atmospheric Research
NO₂	: Nitrogen Dioxide
NOAA	: National Oceanic and Atmospheric Administration
OBS	: Observational Air Pollution Data
OIZ	: Organized Industrial Zone
PM₁₀	: Particulate Matter Smaller Than 10 µg/m ³
PM_{2.5}	: Particulate Matter Smaller Than 2.5 µg/m ³
PPP	: Purchasing Power Parity
TEM	: Trans European Motorway
TSMS	: Turkish State Meteorological Service
TURKSTAT	: Turkish Statistical Institute
US	: United States
VSL	: Value of Statistical Life
WRF-Chem	: Weather Research and Forecasting Model Coupled to Chemistry
WSD	: Wind Speed and Direction



SYMBOLS

%	: Percent
°	: Degree
°C	: Celsius
kg	: Kilogram
m³	: Cubic Metre
mm	: Millimetre
µg / m³	: Micrograms / Cubic Meter
µg	: Microgram



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SOCIO-ECONOMIC IMPACT ANALYSIS OF AIR POLLUTION REDUCTION SCENARIOS WITH BENMAP-CE PROGRAM: DILOVASI EXAMPLE

SUMMARY

Air pollution is called an environmental situation that harms living things as a result of polluting gases and substances in the atmosphere exceeding a certain level. Air pollution, directly and indirectly, affects the living things living in our world and is a global environmental disaster. The causes of air pollution can be shown as anthropogenic emissions and natural origin emissions. The main anthropogenic emissions are the consumption of fossil fuels, industrial activities and vehicles used in transportation. Naturally sourced emissions can be shown as volcanic eruptions, dust storms, sea salt emissions and forest fires.

The problem of air pollution is thought to have started with the discovery of fire, because heating and warming activities started with the discovery of fire, followed by volcanic eruptions, which is thought to cause increases in air pollution. It is known that the first regulation with air pollution was made by King Edward I in the United Kingdom with the prohibition of coal. It is known that the first book written on air pollution was the author John Evelyn's *Fumifugium*, which was published in London in 1661. The increase in air pollution in the world has occurred with the acceleration of science and technology in the last few centuries. Especially after a big event such as the industrial revolution, the UK, China, USA etc. This has led to a rapid increase in emission levels in developed countries.

The study area examined in this thesis is the Dilovası district of Kocaeli. Dilovası district was separated from Gebze in 2008 and turned into a district. Dilovası has a population of 51,060 and an area of 118 km². There are 5 organized industrial zones and 1 industrial site in the district. One of the main causes of air pollution in the district is the industrial activities in OIZs and industrial sites. In this context, Dilovası district is also known for cardiovascular diseases, cancer cases and death rates due to air pollution. In many studies examining the relationship between public health and air pollution in the district, it is known that the air pollution levels of Dilovası exceed national and international borders. When the air pollution analyzes in Dilovası are examined, it is understood that the air pollution is mostly caused by particulate matter pollutants. To sample the climate of the Dilovası district, precipitation, temperature and wind speed data between 2014 and 2018 of the meteorological station in Dilovası from TSMS were examined.

This thesis is considered as an output of the existing TÜBİTAK project numbered 117Y298, the main research question of this graduation thesis is to investigate the socio-economic outputs of improving the air quality of the Dilovası district of the alternative route road created with the intelligent transportation system determined as one of the project objectives.

This thesis aims to examine the socioeconomic consequences of the change in air pollution with the BenMAP-CE program as a result of the intelligent transportation system scenarios created to reduce air pollution in the Kocaeli-Dilovası region, which is known for its intense air pollution. The original value of the thesis is the use of both the air pollution measurement data of the BenMAP-CE program and the gridded data of the atmospheric chemical model WRF-Chem as input data while examining the socioeconomic results of a region like Dilovası in Turkey.

In the air quality analyses carried out between 2014 and 2018 within the scope of the TÜBİTAK project, it was seen that the air pollution of Dilovası district is at levels that threaten public health and transportation emissions are one of the main emission sources. It is aimed to create an intelligent transportation system, which is an environmental and technological solution for transportation emissions. For this intelligent transportation system, it is planned to create an alternative highway route to the TEM highway. Pollution reduction scenarios have been created for this highway in this context. In these scenarios, it is planned to intervene in the heavy traffic with information services to the drivers, with or without redirection to the alternative route.

In this thesis, air pollution reduction scenarios that make the smart transportation system an efficient and responsive system are discussed. These scenarios are called as Air Quality Index ITS scenario and Wind Speed and Direction ITS scenario respectively. In the first stage of the Wind Speed and Direction scenario, the prevailing wind speed and wind direction analysis were made by using the wind speed and wind direction data measured in the Dilovası district. In the second stage, the algorithm scheme for the scenario was created. In the third stage, the percentage of guiding to the new highway route according to the wind direction was calculated. In the last stage, the BenMAP-CE program was used to calculate the socioeconomic results of the improvement. For the air quality index smart transportation system scenario, in the first stage, PM₁₀, NO₂ and CO pollutants were selected using the pollutant measurements at the air quality station in Dilovası of the MoEU, and an air quality index calculation formulation was created. In the second stage, index calculations were made. According to this index, the decision algorithm scheme was created. In the third stage, the percentage of guiding to new highway route according to the air quality index was calculated, the percentage reduction value was used for BenMAP-CE input. In the last stage, the BenMAP-CE program was used to calculate the socioeconomic results of the percentage improvement.

The AQI scenario was created by considering the most threatening pollutants in terms of public health and also caused by the transportation emissions in the region. In the scenario setup, it is planned to calculate the air quality index by taking hourly measurements of PM₁₀, NO₂ ve CO pollutants from the Kocaeli-Dilovası air quality station, which is located between the D-100 and TEM highways of the MoEU. If the AQI result was not between 0-50 (good), it was planned to guide to the alternative route. For the scenario, the air quality index of pollutants measured in 2018 was evaluated and the number of times the limit values were exceeded for the air quality index was considered.

The Wind Direction and Speed scenario was created according to wind speed and direction data of 2018. In this scenario, it was planned to direct to an alternative route if the wind direction was not in the direction of the prevailing wind. For this scenario, the prevailing wind direction was analysed by using the wind speed and direction data measured in the Dilovası district in 2018 by TSMS.

In the socio-economic analysis of the scenarios, EPA's BenMAP-CE program was used for calculations. BenMAP-CE is a program that presents socioeconomic outcomes in the fields of health and economy related to health, simply based on the improvement in air quality (percentage of reduction in air pollution) over the current air pollution values in the target region. For this, possible air pollution reduction values were calculated as a percentage, together with the guidance in the scenarios. The input data of the program are health data, population data, measurement data of the target pollutant, causal mortality data in the region, economic valuation data and finally the percentage of air pollution reduction data in the determined scenario. All data used in the BenMAP-CE program belong to 2018 and socioeconomic calculations were made over this year. The datasets are respectively obtained from TURKSTAT, Ministry of Environment and Urbanization and the World Bank. There are two different data sets used for air pollution data (PM_{10}) used as input in BenMAP-CE: Station measurement data from MoEU and grid pollutant data from the WRF-Chem model. The BenMAP-CE program is based on two basic functions when making its calculations, are the Health Impact Function and the Economic Evaluation Function, respectively. Thanks to these two functions, the BenMAP-CE program provides statistical output in the field of economics and health. As a result of the BenMAP-CE experiments conducted for the scenarios, it is seen that the increase in the percentage of improvement in air quality reduces deaths due to air pollution in the short term (5-10 years) and reduces the economic resources spent on health. In the long run, it is estimated that the amount of money that will be spent to improve the air quality in the region (for the creation and implementation of the smart transportation system) is less than the amount that will be saved as a result of the improvement. In this way, while there will be a positive development in terms of public health, the scenarios created in this thesis will have the air pollution levels of the coming years under some control.

Hourly pollutant data (PM_{10}) for 2018 belonging to the grids within the Kocaeli borders of the WRF-Chem output were given as input to the BenMAP-CE program. It has been introduced as a new approach in addition to the measurement data for socioeconomic analysis with the BenMAP-CE. The data used as meteorological input to the WRF-Chem model is the hourly data of the 0.25-degree GDAS (Global Data Assimilation System) model produced by NOAA for 2018. The output from the WRF-Chem model is in the form of hourly PM_{10} data, and GOCART and EDGAR-HTAP emission data are used as inputs for the background emissions of the model and the horizontal resolution of the model output is 4 km.

One of the biggest advantages of the study is that it is the first study conducted with BenMAP-CE in Turkey, however, default options are generally used for air pollution data in the program. Although the importance of air pollution is known to people, in this study, a program such as BenMAP-CE has shown how effective the results of air pollution change are in terms of economy and health. Contrary to this, it is not sufficient to examine only the economy and health, and it is necessary to add to these areas. As a result, it is thought that public awareness can be increased against air pollution and climate change, which are specially sourced by anthropogenic emissions. In future studies, a similar socioeconomic analysis can be made with this program for other regions/cities with low air quality in Turkey, and it is considered that socioeconomic analysis of climate model scenarios created according to possible emission increases in the future.



HAVA KİRLİLİĞİ AZALTMA SENARYOLARININ BENMAP-CE PROGRAMI İLE SOSYO-EKONOMİK ETKİ ANALİZİ: DİLOVASI ÖRNEĞİ

ÖZET

Hava kirliliği, atmosferdeki kirlenici gaz ve maddelerin belirli bir seviyeyi aşması sonucunda canlı yaşamına zarar veren durum olarak adlandırılır. Hava kirliliği, Dünyamızda yaşayan canlıları direkt ve dolaylı yoldan etkilemektedir ve küresel bir çevre felaketidir. Hava kirliliğinin nedenleri antropojenik kaynaklı emisyonlar ve doğal kaynaklı emisyonlar olarak gösterilebilmektedir. Antropojenik kaynaklı emisyonların başında fosil yakıtların tüketilmesi, endüstriyel faaliyetler ve ulaşımında kullanılan taşıtlar gelmektedir. Doğal kaynaklı emisyonlar ise volkanik patlamalar, toz fırtınaları, deniz tuzu emisyonları ve orman yangınları olarak gösterilebilir.

Kaynaklar birçok faktöre göre sınıflandırılmakla birlikte hava kirliliği kaynakları en çok ölçülerine göre üç sınıfta incelenmektedirler. Bu sınıflandırmada hava kirliliği kaynakları noktasal kaynaklar, çizgisel kaynaklar ve alansal kaynaklar olarak üç sınıfta incelenmektedirler. Noktasal Kaynaklara örnek olarak organize sanayi bölgelerindeki fabrikalar ve endüstriler verilmektedir, bu kapsamda en çok karbon oksitler, metal oksitler ve azot oksit kirliliğine neden olurlar. Çizgisel kaynakların temelinde hava, raylı sistemler ve kara ulaşım araçlarının sebep olduğu kirlilik söz konusudur, buradaki kirliliği hidrokarbonlar, partiküler madde, azot oksitler ve kükürt oksitler oluşturmaktadır. Son olarak, alansal kaynaklar içerisinde evsel ısınma faaliyetleri yer almaktadır, bu faaliyetler sonucunda partiküler madde (PM₁, PM_{2.5} ve PM₁₀) ve kükürt oksitler atmosfere salınmakta aynı zamanda iç ortam hava kalitesini de oldukça etkilemektedir.

Hava kirlenitçileri birincil kirlenitçiler ve ikincil kirlenitçiler olarak ikiye ayrılır. Birincil kirlenitçiler direkt kaynaktan atmosphere salınımla oluşur, ikincil kirlenitçiler ise birincil kirlenitçilerin formasyonu ile meydana gelir. Birincil kirlenitçiler karbon bileşikleri (CO, CO₂, CH₄) ve VOCs; azot bileşikleri (NO, N₂O, NH₃); kükürt bileşikleri (H₂S, SO₂); partiküler madde (PM₁, PM_{2.5} ve PM₁₀ vb.) olarak sınıflandırılabilir. İkincil kirlenitçiler ise NO₂, O₃, H₂SO₄ ve nitrik asit damlacıkları olarak örneklenmektedir.

Hava kirliliği sorununun, ateşin bulunmasıyla birlikte başladığı düşünülmektedir, çünkü ateşin bulunmasıyla ısıtma ve ısınma faaliyetleri başlamıştır, bunu takiben volkanik patlamalarla birlikte hava kirliliğinin artışlarına sebep olduğu düşünülmektedir. Hava kirliliği ile ilk regülasyon Birleşik Krallık'ta Kral I. Edward tarafından kömürün yasaklanmasıyla yapıldığı bilinmektedir. Hava kirliliği üzerine yazılan ilk kitap ise yazar John Evelyn'in Fumifugium adlı 1661'de Londra'da basılan kitabı olduğu bilinmektedir. Dünyadaki hava kirliliğinin artışı son birkaç yüzyıldaki bilim ve teknolojiye hızlanmayla birlikte meydana gelmiştir. Özellikle sanayi devriminin arkasından Birleşik Krallık, Çin, ABD vb. gelişmiş ülkelerdeki emisyon seviyelerinin hızla artışına yol açmıştır.

Bu tezde incelenen çalışma alanı Kocaeli'ne bağlı Dilovası ilçesidir. Dilovası ilçesi 2008 yılında Gebze'den ayrılp bir ilçe haline getirilmiştir. Dilovası'nın nüfusu 51.060'dır ve yüzölçümü 118 km²'dir. İlçede 5 organize sanayi bölgesi ve 1 sanayi sitesi bulunmaktadır. Dilovası'ndaki hava kirliliğinin temel sebeplerinden biri buradaki endüstriyel faaliyetlerdir. Buna bağlı olarak, Dilovası ilçesi aynı zamanda hava kirliliğine bağlı kardiyovasküler hastalıklar, kanser vakaları ve ölüm oranları ile bilinmektedir. İlçede halk sağlığının hava kirliliği ile ilişkisini inceleyen birçok çalışmada Dilovası hava kirliliğinin ulusal ve uluslararası sınırları aştığı bilinmektedir. Dilovası'nda kirlilik analizleri incelendiğinde hava kirliliğinin çoğunlukla partiküler madde kirliliği olduğu anlaşılmaktadır. Dilovası bölgesinin iklimini örnekleyebilmek için Dilovası'ndaki meteoroloji istasyonuna ait 2014 - 2018 arası yağış, sıcaklık ve rüzgar hızı verileri incelenmiştir.

Bu bitirme çalışması, varolan 117Y298 nolu TÜBİTAK projesinin bir çıktısı olarak düşünülürse, proje amaçlarından biri olarak belirlenen akıllı ulaşım sistemi ile oluşturulan alternatif güzergah yolunun Dilovası ilçesinin hava kalitesinin iyileştirilmesinin sosyo-ekonomik çıktıların araştırılması bu bitirme tezinin ana araştırma sorusudur.

Bu tezin amacı ise yoğun hava kirliliği ile bilinen Kocaeli-Dilovası bölgesinin hava kirliliği azaltılması için oluşturulan akıllı ulaşım sistemi senaryolarının sonucunda BenMAP-CE programı ile hava kirliliğindeki değişimin sosyoekonomik sonuçlarını incelemektir. Tezin özgün değeri ise Türkiye'de daha önce Dilovası gibi bir bölgenin sosyoekonomik sonuçları incelenirken BenMAP-CE programının bölgeye ait hem hava kirlilik ölçüm verisinin hem de atmosferik kimyasal model WRF-Chem'in gridlenmiş verisinin girdi verisi olarak kullanılmasıdır.

TÜBİTAK projesi kapsamında 2014-2018 arası yapılan hava kalite analizlerinde Dilovası ilçesinin hava kirliliğinin, halk sağlığını tehdit eden seviyelerde olduğu görülmüştür. İlçedeki emisyon kaynaklarından biri olan ulaşım kaynakları için çevresel ve teknolojik bir çözüm olan akıllı ulaşım sistemi oluşturulması amaçlanmıştır. Bu akıllı ulaşım sistemi için TEM otoyoluna alternatif olan bir otoyol güzergahı oluşturulması planlanmıştır. Bu otoyol için kirlilik azaltıcı senaryolar yaratılmıştır. Senaryolarda yoğun trafiğe sürücülere bilgilendirme hizmetleriyle alternatif güzergaha yönlendirme veya yönlendirme olmadan müdahale edilmesi planlanmaktadır.

Bu tezde akıllı ulaşım sisteminin verimli ve hızlı yanıt verebilen bir sistem olmasını sağlayan hava kirliliği azaltma senaryoları ele alınmıştır. Bu senaryolar sırasıyla Hava Kalite İndeksine göre oluşturulan senaryo ve Rüzgar Hızı ve yönüne göre oluşturulan senaryodur. Oluşturulan iki hava kirliliği azaltma senaryolarından birisi olan rüzgar hızı ve yönü senaryosu için ilk aşamada Dilovası ilçesinde ölçülen rüzgar yönü ve rüzgar şiddeti verileri kullanarak hakim rüzgar yönü ve rüzgar şiddeti analizi yapılmıştır. İkinci aşamada algoritma şeması oluşturulmuştur. Üçüncü aşamada rüzgar yönüne göre yönlendirme, yüzdesel veri olarak hesaplanmıştır. Son aşamada yüzdesel iyileştirmenin sosyoekonomik sonuçlarının hesaplanabilmesi için BenMAP-CE programı kullanılmıştır. Hava kalite indeksi akıllı ulaşım sistemi senaryosu için ilk aşamada ÇŞB'nin Dilovası'nda yer alan hava kalite istasyonundaki kirlleticiler ölçümleri kullanılarak PM₁₀, NO₂ ve CO kirleticileri seçilip hava kalite indeks hesaplama formülasyonu oluşturulmuştur. İkinci aşama olarak endeks hesaplamaları yapılmıştır. Bu endekse göre karar algoritma şeması oluşturulmuştur. Üçüncü aşamada endekse göre yönlendirme sonucunda hava kirliliği azalımı yüzdesel olarak hesaplanmıştır.

Son aşamada yüzdesel iyileştirmenin sosyoekonomik sonuçlarının hesaplanabilmesi için BenMAP-CE programı kullanılmıştır.

Hava kalite endeksinde göre oluşturulan senaryo, bölgedeki ulaşım emisyonlarından çıkan ve bölgedeki en çok kirlilik yaratan kirleticiler göz önüne alınarak oluşturulmuştur. Oluşturulan senaryo kurgusunda ise ÇŞB'ye ait D-100 ve TEM otoyollarının arasında yer alan Kocaeli-Dilovası hava kalite istasyonundan PM₁₀, NO₂ ve CO kirleticilerinin saatlik ölçümler alınıp hava kalite indeksi hesaplanması planlanmıştır, bunun sonucunda eğer endeks sonucu 0-50 arasında ve iyi kategorisinde yer almıyorsa alternatif güzergaha yönlendirme yapılması planlanmıştır. Senaryo için 2018 yılına ait hava kalite indeksi değerlendirmesi yapılarak hava kalite indeksi için limit değerlerin kaç kere aşıldığı göz önüne alınmıştır.

Rüzgar Yönü ve Hızı senaryosu, 2018 yılına ait rüzgar yönü ve rüzgar şiddeti verilerinin analizi sonucunda belirlenen hakim rüzgar yönü ve rüzgar şiddetine göre oluşturulmuştur. Bu senaryoda da anlık rüzgar ölçüm verisine göre hakim rüzgar yönünde olup olmamasının değerlendirilmesi sonucunda alternatif güzergaha yönlendirme yapılması planlanmıştır. Bu senaryo için MGM'nin 2018 yılında Dilovası ilçesinde ölçtüğü rüzgar yönü ve rüzgar şiddeti verileri kullanarak hakim rüzgar yönü ve rüzgar şiddeti değerlendirmesi yapılmıştır. Bu aşamada rüzgar hız dağılımı ve rüzgar gülleri göz önüne alınmıştır.

Senaryolara ait analizlerde sosyoekonomik hesaplamaları için EPA'ya ait BenMAP-CE programı kullanılmıştır. BenMAP-CE, basitçe hedef bölgedeki mevcut hava kirliliği değerleri üzerinden hava kalitesindeki iyileşmeyi (hava kirliliğindeki azalış yüzdesini) baz alarak sağlık ve ekonomi alanlarında sosyoekonomik çıktıları sunan bir programdır. Bunun için senaryolardaki yönlendirmelerin yapılmasıyla birlikte olası hava kirliliği azalış değerleri yüzdesel olarak hesaplanmıştır. Programın girdi verileri sağlık verileri, popülasyon verileri, hedef kirleticinin ölçüm verileri, bölgedeki nedensel ölüm oran verileri, ekonomik değer verileri ve son olarak belirlenen senaryodaki yüzdesel hava kirliliği azalış verisidir. BenMAP-CE programında kullanılan bütün veriler 2018 yılına ait veriler olup sosyoekonomik hesaplamalar bu yılın üzerinden yapılmıştır. Veriler sırasıyla TÜİK, T.C. Çevre ve Şehircilik Bakanlığı ve Dünya Bankası'ndan alınmıştır. BenMAP-CE'de girdi olarak kullanılan hava kirliliği verisi (PM₁₀) için kullanılan iki farklı veri seti mevcuttur: İstasyon ölçüm verileri ve WRF-Chem modelinin gridli kirletici veri seti. Diğer girdi verileri için tek türde veri setleri kullanılmıştır. BenMAP-CE programı hesaplamalarını yaparken iki temel fonksiyonu baz almaktadır, bunlar sırasıyla Sağlık Etki Fonksiyonu ve Ekonomik Değerlendirme Fonksiyonudur. BenMAP-CE programı bu iki fonksiyon sayesinde ekonomik ve sağlık alanında istatistiksel çıktı vermektedir. Senaryolar için yapılan BenMAP-CE deneyleri sonucunda hava kalitesindeki iyileşme yüzdesinin artışı, kısa vadede (5-10 yıl) hava kirliliği nedenli ölümleri azalttığı ve sağlık için harcanan ekonomik kaynakları azalttığı görülmektedir. Uzun vadede ise bölgedeki hava kalitesini arttırmak amaçlı harcanacak olan (akıllı ulaşım sisteminin oluşturulması ve hayata geçirilmesi için) para tutarının, iyileşme sonucunda tasarruf edilecek olan tutardan odaha az olduğu tahmin edilmektedir. Bu şekilde hem toplum sağlığı adına olumlu bir gelişme yaşanırken aynı zamanda bu tezde oluşturulan senaryolar gelecek yılların hava kirliliği seviyeleri bir nebze kontrol altına alınmış olacaktır.

WRF-Chem çıktısının Dilovası sınırlarının içinde kalan gridlere ait 2018 yılı için saatlik kirletici verilerinin (PM₁₀) BenMAP-CE programına girdi olarak verilmiştir.

Oluşturulan iki hava kirliliği azaltma senaryosunun son aşaması olan BenMAP-CE programı ile sosyoekonomik analiz için ölçüm verisine ek olarak yeni bir yaklaşım olarak getirilmiştir. WRF-Chem modeline meteorolojik girdi olarak kullanılan veri NOAA'nın üretmiş olduğu 0.25 derecelik GDAS (Global Data Assimilation System) modelinin 2018 yılına ait saatlik verisidir. WRF-Chem modelinden alınan çıktı saatlik PM₁₀ verisi şeklinde olup modelin arkaplan emisyonları için GOCART ve global emisyon envanteri olan EDGAR-HTAP emisyon verileri girdi olarak kullanılmıştır ve model çıktısının yatay çözünürlüğü 4 km'dir.

Çalışmanın en büyük avantajlarından biri Türkiye'de BenMAP-CE ile yapılan ilk çalışma olmasıdır, bununla birlikte programda hava kirliliği verileri için genellikle default seçenekler kullanılmıştır. Hava kirliliğinin insanlar tarafından öneminin bilinmesine rağmen bu çalışmada BenMAP-CE gibi bir program hava kirliliği değişim sonuçlarının ekonomi ve sağlık açısından ne kadar etkili olduğunu göstermiştir. Bununla ters olarak, sadece ekonomi ve sağlık açısından incelenmesinin yeterli olmadığı, bu alanlara ekleme yapılması gerekmektedir. Bunun sonucunda hava kirliliği ve iklim değişikliği gibi özellikle antropojenik kaynaklı olan bu iki çevresel olaya karşı toplum farkındalık artırılabilceği düşünülmektedir. Gelecek çalışmalarda Türkiye'de hava kalitesinin düşük olduğu diğer bölgeler/şehirler için bu program ile benzer bir sosyoekonomik analiz yapılabilir olmakla birlikte gelecekte olası emisyon artışlarına göre oluşturulan iklim model senaryolarının sosyoekonomik analizlerinin de yapılması düşünülmektedir.

1. INTRODUCTION

Air pollution is an environmental problem that harms living things as a result of polluting gases and substances in the atmosphere exceeding a certain level. Air pollution, directly and indirectly, affects the living things living in our world and is a global environmental disaster (İncecik, 1994).

The causes of air pollution can be examined as anthropogenic emissions and natural emissions. The anthropogenic emissions are mainly related to the consumption of fossil fuels, industrial activities and vehicles used in transportation. Volcanic eruptions, dust storms, sea salt emissions and forest fires are examples of natural emissions (Toros, 2000).

Although the pollutant sources are classified according to many factors, the sources of air pollution are mostly examined in three classes according to their dimensions. In this classification, air pollution sources are examined in three classes as point sources, linear sources and areal sources (Bespalov et al., 2019.). Factories and industries are examples of point sources, in this context, they mostly cause carbon oxides, metal oxides and nitrogen oxide pollution (İncecik, 1994). The basis of linear sources is pollution caused by air, rail and land systems, the pollution caused by linear sources is mainly composed of hydrocarbons, particulate matter, nitrogen oxides and sulfur oxides (Şen, 1997). Finally, areal sources include house heating activities. As a result of these activities, particulate (PM_1 , $PM_{2.5}$ and PM_{10}) and sulfur oxides are released into the atmosphere and also affect indoor air quality considerably (Lin et al., 2018).

Air pollutants are divided into primary pollutants and secondary pollutants. Primary pollutants are formed by direct emission from the source to the atmosphere, and secondary pollutants are formed by the formation of primary pollutants. Primary pollutants can be classified as carbon compounds (CO , CO_2 , CH_4) and VOCs, nitrogen compounds (NO , N_2O , NH_3), sulfur compounds (H_2S , SO_2) and particulate matter (PM_1 , $PM_{2.5}$ ve PM_{10} etc.). Secondary pollutants are exemplified as NO_2 , O_3 , H_2SO_4 and nitric acid droplets (Daly & Zannetti, 2007).

Particulate matter is divided into 5 groups in terms of particle size: particles smaller than 100 microns (PM_{100}), particles smaller than 10 microns (PM_{10}), particles smaller than 4 microns (PM_4), particles smaller than 2.5 microns ($PM_{2.5}$) and particles smaller than 0.1 microns. particles ($PM_{0.1}$). PM_{100} usually contains dust particles of natural origin and can easily enter through the nose and mouth. PM_{10} , on the other hand, are called fine particles and are also thoracic because they penetrate deep into the respiratory tract. The PM_4 group includes particulate matter in the respirable category because these particles can completely pass through the respiratory system and easily enter the human body's bloodstream. $PM_{2.5}$ and PM_1 groups are classified as fine and ultrafine in the U.S, respectively (Daly & Zannetti, 2007).

It is known that particulate matter, associated with many cardiovascular and respiratory diseases, increases acute respiratory hospital admissions and causes premature deaths. Health problems caused by particulate matter are examined in three groups: clinical cases, toxicology and epidemiology. In terms of toxicology, particulate matter contains heavy metal and oxygenated organic compounds, which cause allergic reactions in the human body and damage to internal organs. One of the damaging factors in particulate matter is size distribution. One of the important ratios in this context is the $PM_{2.5}/PM_{10}$ ratio. This rate varies from big cities to big cities in developed countries, and this directly affects the exposure-response relationship (Harrison & Yin, 2000).

Chronologically, the problem of air pollution is thought to have started with the discovery of fire, because heating and warming activities started with the discovery of fire, followed by volcanic eruptions, which is thought to cause increments in air pollution. It is known that the first regulation with air pollution was made by King Edward I in the United Kingdom with the prohibition of coal. It is known that the first book written on air pollution was the author John Evelyn's *Fumifugium*, which was published in London in 1661 (İncecik, 1994).

Previous studies about the history of air pollution indicate that a chemist named Svante Arrhenius calculated that doubling the carbon dioxide content would increase the overall average temperature on Earth by 5-6 degrees in 1896, but until the 1930s, carbon dioxide emissions could not be correlated with temperature increases (Fenger, 2009). The increase in air pollution in the world has occurred with the acceleration of science and technology in the last few centuries. Especially after a big event such as

the industrial revolution, the UK, China, USA etc. This has led to a rapid increase in emission levels in developed countries. According to the air pollution measurement study made in the capitals of most of the countries around the world between 1976-80, one out of three capitals exceeded the daily average SO₂ limit value (100- 150 µg/m³) and daily suspended particulate matter concentration limit value (150-230 µg/m³) is exceeded by one of the two capitals (Bennett et al., 1985).

In an air pollution study conducted in Europe between 1990 and 2012, the pollution levels in Western Europe and Eastern Europe have changed according to the development levels of the countries located here, the increase in the use of renewable energy sources and the environmental compliance laws enacted by the European Commission. It was stated that the pollutant emissions of Western Europe tended to decrease continuously in this process compared to Eastern Europe, in contrast, there was an increase in emissions in Eastern Europe, especially in the mid-1990s (Colette et al., 2016). The study by Amann et al. reports that it is predicted that global anthropogenic SO₂ emissions can be reduced by 35% and NO_x and primary PM_{2.5} emissions by approximately 10% by 2040 if timely implementation and full compliance are achieved according to the Clean Air Scenario legislation decided until 2018 (Amann et al., 2020).

1.1 Purpose of Thesis

The main research proposal is to investigate the socio-economic impact of improving the air quality of Dilovası district with the smart transportation system application by using alternative road routes to E-5 and D-100. This study aims to examine the change of death cases caused by air pollution and health cost after possible air pollution reduction scenarios with the BenMAP-CE program. The program is executed with pollutant measurement data and also WRF-Chem model data for the Dilovası district.

The original value of the thesis is the investigation of the possible socio-economic impact of change of air pollution in a region like Dilovası district which is known for its cancer cases caused by extreme air pollution levels with the use of the BenMAP-CE program. Also, this study will be the first Master's thesis about the use of the BenMAP-CE program in Turkey. Another significant point is to use two different air pollution datasets as input data (MoEU's pollutant measurement data and WRF-Chem

model gridded data) for the BenMAP-CE program while examining the socioeconomic results of Dilovası district.

1.2 Literature Review

Kocaeli- Dilovası region is one of the most polluted areas in Turkey in terms of air pollution. The air pollution is mainly caused by industrial areas, dense traffic and poor house heating choices in this region. The causes of death in Dilovası are believed to be connected with the concentrated industrial areas in the Dilovası region. It was also stated that the death rates from cancer in the region were 3 times higher than the average of both Turkey and the world (Hamzaoglu et al., 2011). Particulate matter pollution is believed to be the main reason for air pollution in the Dilovası region (Yılmaz et al., 2020a). In the particulate matter pollution study in Gebze-Dilovası, the breakdown of pollutant sources and particulate carcinogenic chamber (polycyclic aromatic hydrocarbon) analysis were performed, Considering the PAH results, it was determined that the pollution in Dilovası was approximately 10 times higher than in Gebze (Sivaslıgil, 2007). One study about Dilovası, it was examined the sociological view of industrialization and urbanization. It has been emphasized that the region is constantly on the agenda with environmental problems and that it is known for deaths caused by air pollution (Kolukirik, 2012).

In the literature review about health impact assessments, it can be seen that there are so many open-source and publicly available assessment tools like BenMAP-CE. In one study about the use of these helping tools, it is mentioned that during May 2014 WHO gathering, 12 multinational assessment tools like BenMAP-CE, AirQ+, SIM-Air, GMAPS are examined, categorized by their definitions, technical and operational characteristics and obstacles (Anenberg et al., 2016).

BenMAP-CE is one of these benefit analysis tools, has been developed by U.S Environmental Protection Agency (U.S EPA, 2021). The use of BenMAP-CE can be used by various users like policymakers, decision-makers and air quality scientists. One study by Qiu et al. has performed a health impact assessment including all US states and cities with SMAT-CE and BenMAP-CE programs for policymaking reasons by creating emission control scenarios (2015).

The air pollution levels in Asian countries are known as unhealthy levels for human health, therefore the Asia domain is one of the most frequently used domain areas in BenMAP-CE configuration in recent years. The research made for Guangzhou Asian Games in China in November 2010 by Ding et al. shows the health impact analysis of the Guangzhou government's emission control strategies due to persistent pollution dispersion caused by meteorological conditions, the study demonstrated 106 premature deaths, 1869 cases of hospital admission can be avoided with reduction by $3.5 \mu\text{g}/\text{m}^3$ in $\text{PM}_{2.5}$ levels (2016). As (Bae & Park, 2009) Bae and Park underline a health benefits analysis with the generalized additive model (GAM) and BenMAP-CE tools for public health of Korean society. Whereas GAM model was used to assess the relationship between daily mortality and air pollution, BenMAP-CE was used for health exposure analysis of ozone and PM_{10} pollutants, the results showed that elderly people (65+) were more likely the high-risk group for acute mortality than people between 0-64 (2009). In addition, (Nawahda, 2013) Nawahda mentioned the possible health outcomes of $\text{PM}_{2.5}$ reductions in Japan by using air quality monitoring data between 2006-2009 for the BenMAP-CE program, the results of the $\text{PM}_{2.5}$ reduction by $10 \mu\text{g}/\text{m}^3$ shows the prevention of 3.602 death cases and %77 of these cases are elder age group of +75 (2013).

There are many examples of other air quality data types used for input dataset. For instance, atmospheric chemistry model outputs are used as inputs for the BenMAP-CE program, one of the common models used for the program is CMAQ by the same institution as BenMAP-CE (U.S EPA, 2021). One CMAQ modelling study in Spain suggest that the use of air quality models in study areas without measurement data would be helpful in terms of health impact assessments. The study concerns two different scenarios (reference as 2007 and projected as 2014) of fine particle reduction by $1 \mu\text{g}/\text{m}^3$ for 2014 and as a result, 8-15 all-caused death cases per 100.000 population of the whole country could be prevented (Boldo et al., 2014). Similarly, two different datasets of modelled and measured air pollution data ($\text{PM}_{2.5}$ and PM_{10}) was used as input for the BenMAP-CE program for Shanghai, China region, the modelled concentrations from the CMAQ model were studied for baseline year (2010) and post-control year (2015) while measured concentrations were studied between 2010 and 2012. The estimated number of avoided all-cause death cases were from 39 to 1400 per year and 6 to 26 cases per day (Voorhees et al., 2014). CAMX model as

an alternative modelling approach was studied by (Fann et al., 2013) to estimation the health burden of air pollution ($PM_{2.5}$ and O_3) in the United States in 2005 and 2016 separately for comparison. In the study, the burden caused by air pollution was distributed into different emission sectors such as mobile, area and international. Even though there are many limitations and uncertainties caused by source apportionment modelling and emission predictions issues, it was found that emissions from the majority of sectors were reduced in 2016 according to 2005. In addition to that, premature deaths related to emissions reduced by %6 in 2016. Lastly, electricity generating units (EGU) and area sources are found to contribute $PM_{2.5}$ more than other emission sources and the mobile sources are more responsible for the ozone concentrations than others.

One of these interesting studies mentions the use of the Community Earth System Model (CESM) and WRF-Chem as global and regional scale models, the model outputs are used for BenMAP-CE to examine the effects of $PM_{2.5}$ and O_3 pollutants on health and economic burden during weather extremes conditions (e.g. heatwaves). The analysis was made for two decades from the past (2001-2010) and the future (2046- 2055) under RCP 4.5 and 8.5 emission scenarios (Zhang et al., 2020). One of the health impact studies of $PM_{2.5}$ and PM_{10} in Brazil stated that since the cities close to the capital doesn't have enough $PM_{2.5}$ data, one-year modelling of $PM_{2.5}$ and PM_{10} is made with the WRF-Chem model for 2015. Results showed that avoidable death cases caused by $PM_{2.5}$ are around 32.000 (Andreão et al., 2020).

1.3 Hypothesis

The two main research questions of this thesis are “How does the air quality improvement affect the death cases and health cost in Dilovası district and Kocaeli city?” and “How does the use of gridded model data as input data for BenMAP-CE result differently from real-time measurement pollutant data?” The first hypothesis regards to the first question would be possible air quality improvement in Dilovası reduces the yearly death cases and also help to save on health costs in the district. The second hypothesis would be the use of the gridded model data for BenMAP-CE will differ in terms of health cost and death cases numbers from the use of real-time measurement data.

2. DATA AND METHODOLOGY

2.1 Study Area

Dilovası is a district of Kocaeli province in the Marmara Region. Dilovası, which has been a town since December 31, 1986, was separated from Gebze and became a district with the law no. 5747 enacted on March 22, 2008 (Kocaeli Metropolitan Municipality, 2017).

As of 2020, the area of the district is 118 km², the population is 51,060 people and the population density are 362,128 people/km². There is Gebze district located in the north and west of Dilovası, Körfez district in the east and Izmit Gulf in the south (Endeksa, 2021).

As shown in Figure 2.1, Dilovası has sea, land and railway networks which are in a very good position in terms of transportation. Dilovası has an important location in Istanbul, connecting the European Side to the Anatolian Side and located on various transportation networks. Dilovası started to gain value after the E-5 state highway, which was built in 1955 and is now called D-100, passes through this region (Dilovası Municipality, 2020). The location of Dilovası between highways called E-80, O-7 and D-100 is shown in Figure 2.2.

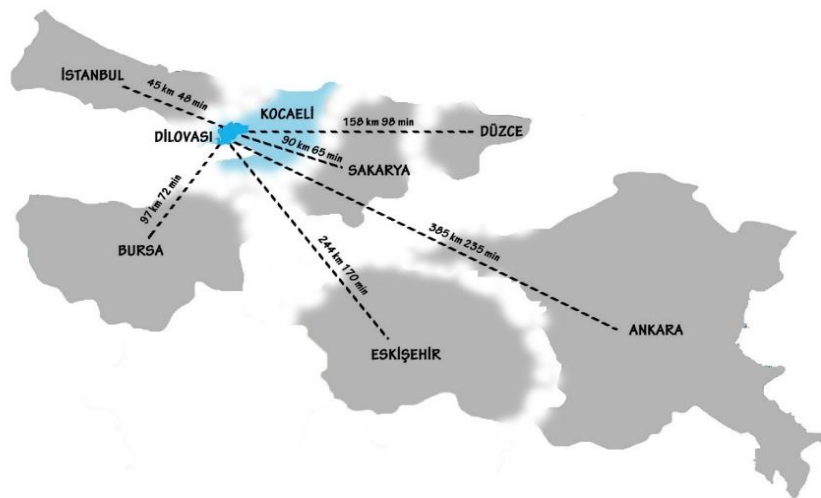


Figure 2.1 : The Map of Kocaeli and Other Cities (Gökmen, 2021).

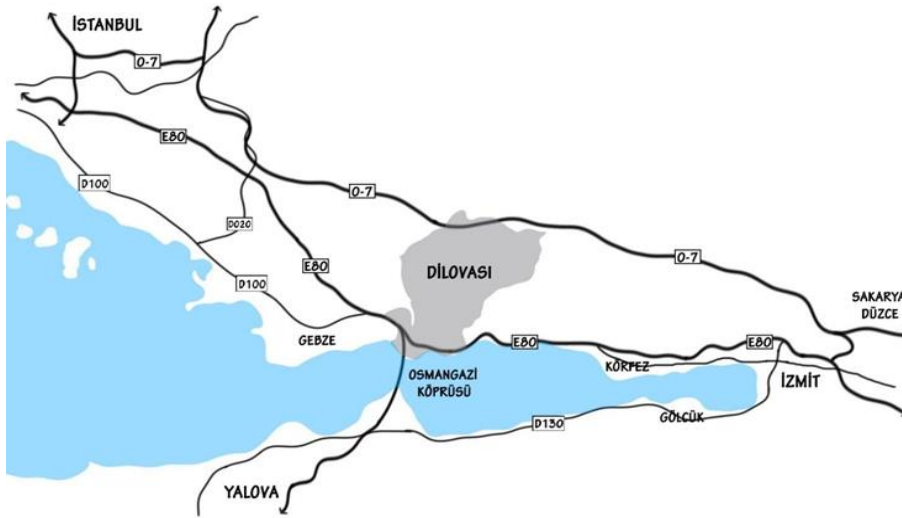


Figure 2.2 : The Map of Dilovası (Gökmen, 2021).

The economy of Dilovası district is based on industry. There are 5 Organized Industrial Zone (OIZ) and 1 industrial site in the district, they can be seen as purple areas in Figure 2.3. Some of the industrial establishments operating in Dilovası are at the top of the list of Turkey's largest industrial establishments. Dilovası is the place of production of many international brands. There is an industrial zone of approximately 2200 hectares in Dilovası. OIZs operating in Dilovası and their hectare sizes can be listed as Dilovası OIZ (822 hectares), IV Makina OIZ (300 hectares), V GEBKİM (Chemists) OIZ (243 hectares), VI İMES OIZ (Machinery Specialized) (300 hectares), Kömürcüler OIZ (78 hectares) and Mermerciler Sanayi Sitesi (270 hectares). These industrial establishments and the number of people employed make a significant contribution to the country's economy (Dilovası District Governorate, n.d). The industrialization activities that started in Dilovası in the 1960s caused the population to increase rapidly with the migration of working people in the 1980s (Dilovası Municipality, 2020). As a result of people's need for shelter, the period of slums and Dilovası began to urbanize. Furthermore, there are 4 main villages in Dilovası region called as Tepecik, Çerkeşli, Köşeler and Demirciler. In these villages, agriculture and livestock can be thought of as the primary source of living in the district (Kocaeli Metropolitan Municipality, 2017). In Figure 2.3, the brown areas represent the living areas and villages in Dilovası.

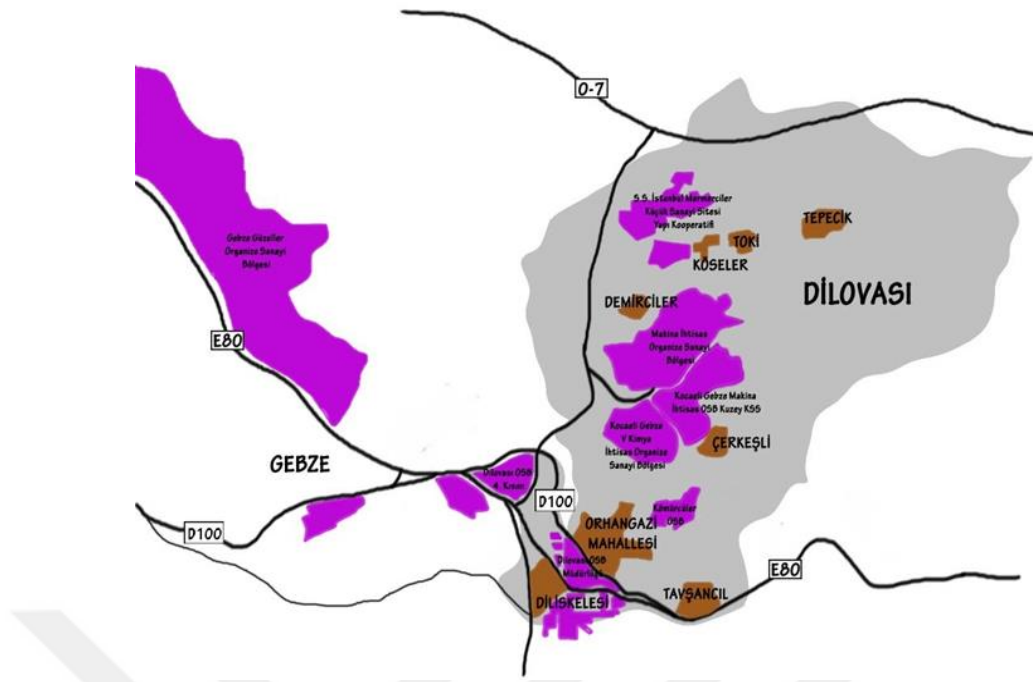


Figure 2.3 : The Map of Dilovası (Gökmen, 2021).

According to Kocaeli Environmental Annual Report 2019, Most of the sectoral emissions originate from industrial facilities and processes in Kocaeli. In addition, greenhouse gas emissions are expected to increase until 2030 due to the expected increment of Kocaeli's population and related production-consumption activities (Kocaeli Provincial Directorate of Environment and Urbanization, 2020).

Similarly, Dilovası's air pollution has been a major environmental problem since the presence of crowded industrial zones and the facilities' overproduction activities in these zones. Additionally, evaluation of air quality in Dilovası made by Yılmaz et al. shows that particulate matter is the main pollutant of unhealthy air quality in Dilovası (Yılmaz et al., 2020b)

Hamzaoglu and Can (2014) examined the relationship between air pollution levels and the risk of lung cancer in those living in Dilovası. Compared to a person living in a clean air area, the risk of developing lung cancer for a person living in Dilovası is 6.5 times more in 2009, 7.1 times more in 2010, 6.4 times more in 2011 and 8.7 times more in 2013. Specifically, the risk of developing lung adenocarcinoma is 9.8 times more in 2009, 10.7 times more in 2010, 9.7 times more in 2011 and 13.1 times more in 2013. It was also stated that average air pollution levels in the region were 3.7 times more in 2009, 3.9 times more in 2010, 3.6 times more in 2011 and 4.6 times more in

2013 than the air pollution limit values determined by the World Health Organization (WHO).

Dilovaşı district is located in the city of Kocaeli, therefore the climate of this district has similarities with the city. While Gulf coasts areas across the Black Sea have a mild climate, mountainous and plain areas of the city have continental climates. It can be said that the climate of Kocaeli constitutes a transition between the Mediterranean climate, Continental climate and the Black Sea climate (Kocaeli Provincial Directorate of Agriculture and Forestry, n.d).

The temperature, precipitation, wind speed and direction data between 2014 - 2018 from the Turkish State Meteorological Service are examined for the climate information of Dilovaşı. In Figure 2.4, the monthly averaged temperature values are seen. According to this, the hottest month is August with the value of 24.65 °C and the coldest month is January with the value of 6.89 °C. The average temperature value of all months between 2014 - 2018 is 15.39 °C.

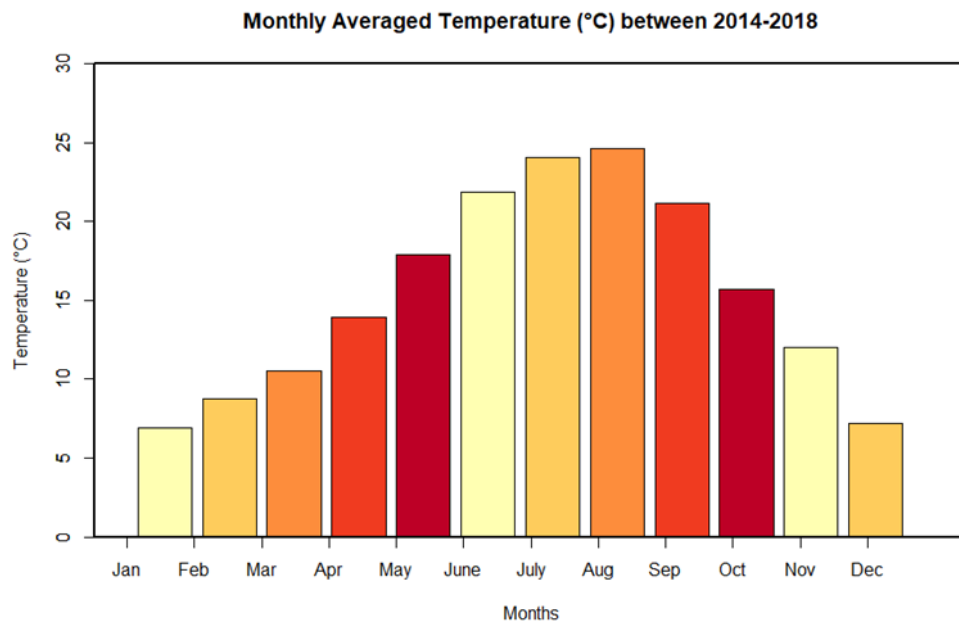


Figure 2.4 : The Monthly Averaged Temperature of Dilovaşı.

In Figure 2.5, the monthly averaged maximum and minimum values of all months between selected years are shown. The red line represents monthly averaged maximum temperature values and the blue line represents monthly averaged minimum temperature values. According to maximum temperature values, the highest values belong to July, September and August respectively. The values of July and September

are quite close, they are both 35 °C. It is suspected that the summer season begins in late June and lasts until September. On the other hand, the lowest values on the blue line are January (-2.70 °C), February (-2.08 °C) and December months (-1.9 °C) respectively. The temperature difference between the minimum and maximum values are between 17 and 23 °C.

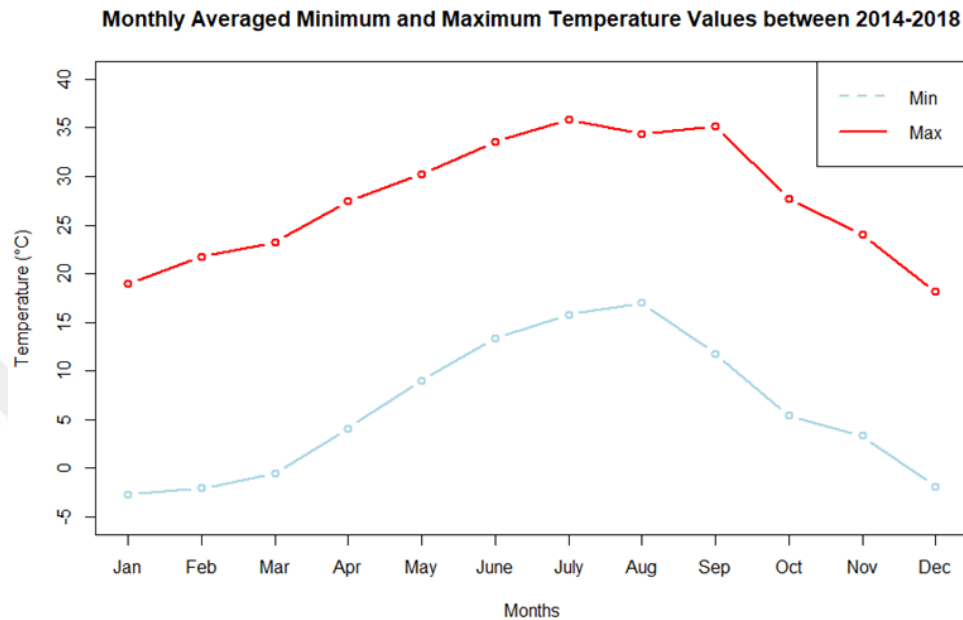


Figure 2.5 : Maximum and Minimum Values of Monthly Averaged Temperature.

The monthly averaged precipitation trend indicates that the maximum precipitation occurs in December months while the minimum precipitation occurs in April months in Figure 2.6. During December and April, there is decreasing trend in precipitation. In May and June months, it shows an increment and the precipitation amount of summer months (July and August) goes back to the value of April.

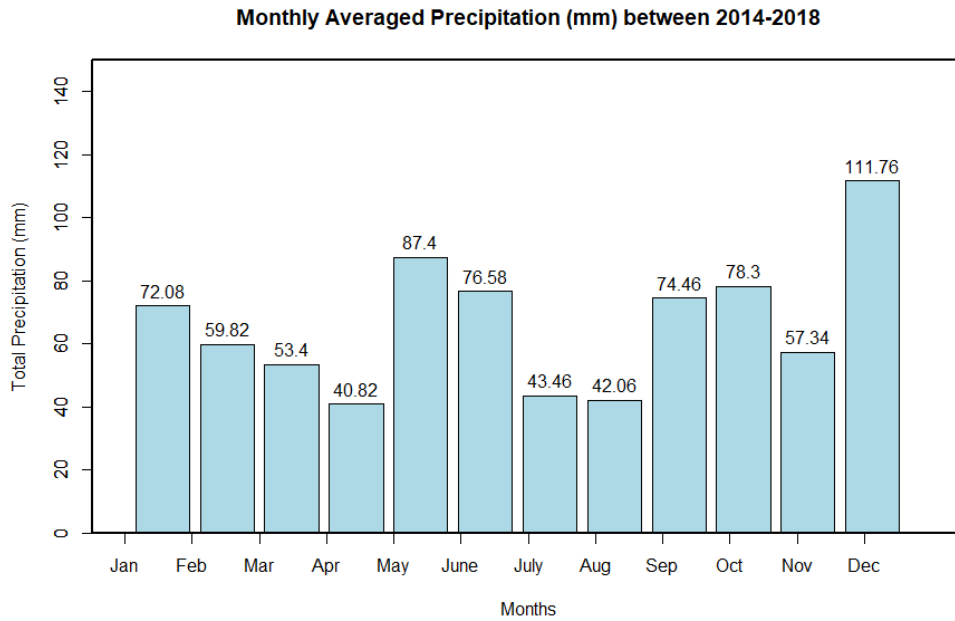


Figure 2.6 : The Monthly Averaged Precipitation of Dilovası.

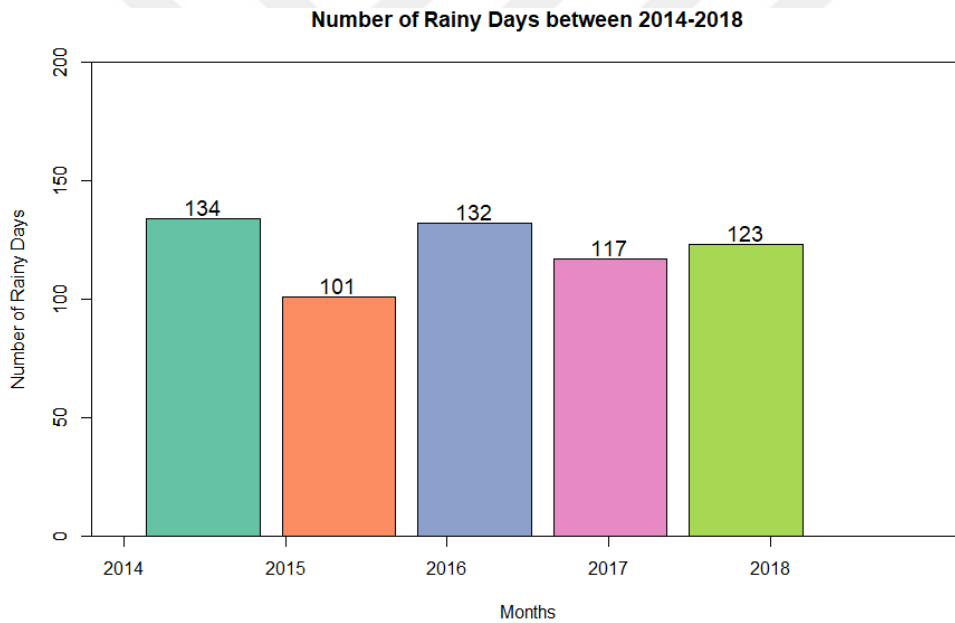


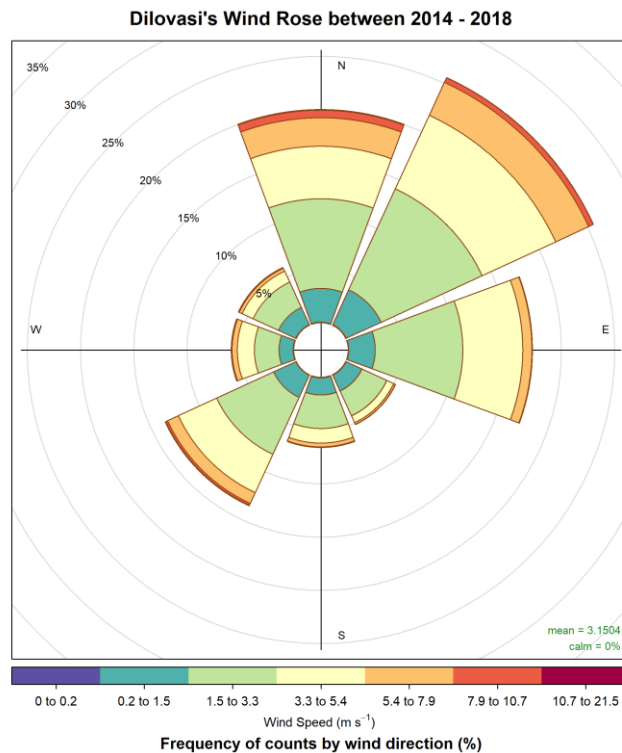
Figure 2.7 : The Number of Rainy Days in Dilovası.

In Figure 2.7, the number of rainy days in a year is shown. About this graph, the least number of rainy days in a year occurs in 2015 and the greatest number occurs in 2014. The average value of the number of rainy days in a year is 121 which is 1/3 of a year. Table 2.1 provides the monthly distribution of the total number of rainy days between 2014 - 2018. As it can be seen, there are two months that precipitation never occurs which are February in 2014 and July in 2015 in 60 months. The highest number of rainy days is shown in December 2017.

Table 2.1 : The Monthly Distribution of Rainy Days.

Years / Months	2014	2015	2016	2017	2018
January	2	11	18	17	15
February	0	13	13	8	13
March	12	13	18	9	13
April	10	15	9	10	3
May	18	8	15	10	13
June	14	10	8	7	6
July	19	0	3	5	11
August	12	4	5	5	1
September	13	6	6	7	10
October	11	10	9	9	7
November	8	5	10	9	11
December	15	6	18	21	20
TOTAL	134	101	132	117	123

Wind speed and direction analysis for Dilovası are separated into 3 different wind rose for climate information. The wind roses are created with hourly wind speed and direction data between 2014 - 2018. As shown in Figure 2.8, the prevailing wind direction of Dilovası for the entire year is north-easterly.

**Figure 2.8 : The Wind Rose of 2014-2018 in Dilovası.**

Northerly and easterly directions are secondary prevailing wind directions. The wind speed reached 21.5 m/s as maximum, there are 57 hourly values lower than 0.2 m/s and 70 hourly values higher than 10.7 m/s in these 5 years. Wind speed between 1.5 - 3.3 m/s is dominant for almost every wind direction and have a rate of 0.41 to all hourly wind speed values.

The seasonal wind speed and direction distribution of Dilovası are shown in Figure 2.9. The distribution of wind in autumn and summer are almost the same and they have the north-easterly winds as prevailing direction. In the autumn and winter seasons, winds higher than 7.9 m/s is increased compared to the spring and summer seasons. As can be seen from spring's wind rose, the south-westerly direction can be considered as secondary wind direction after the north-easterly and easterly direction.

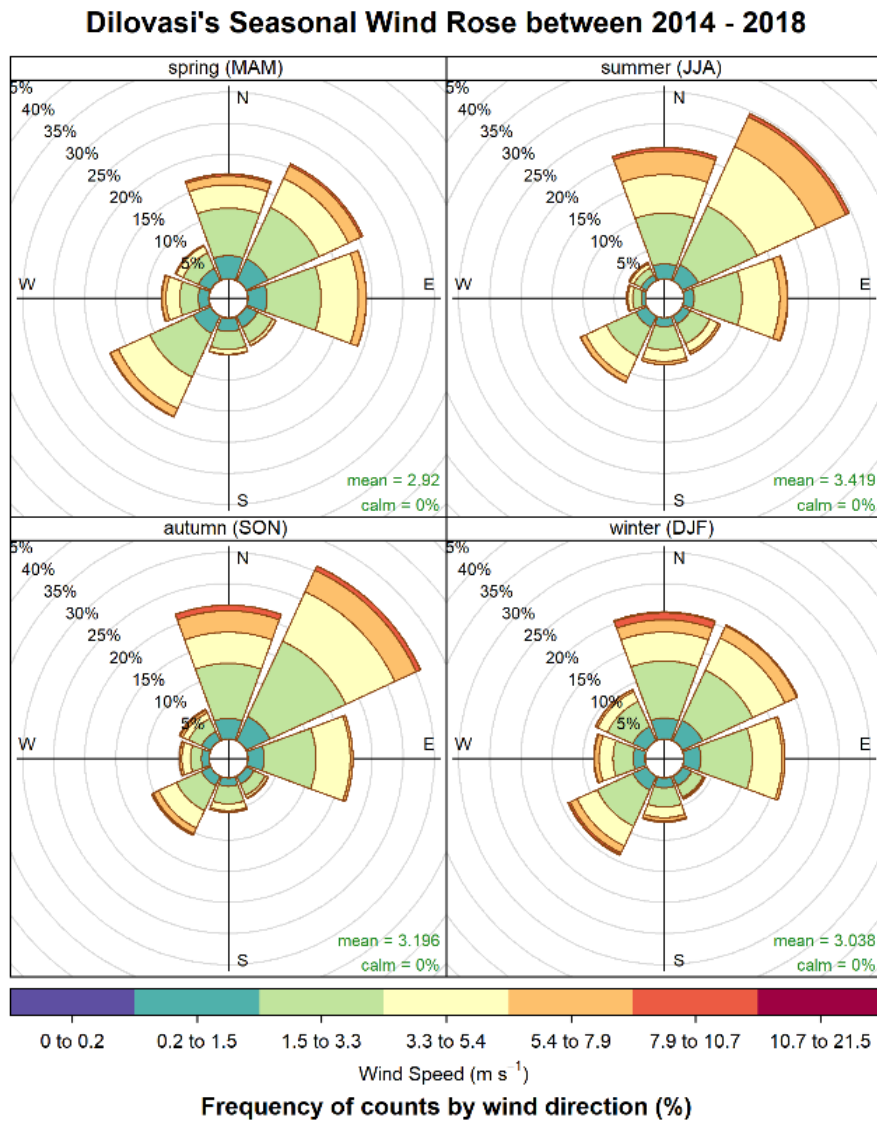


Figure 2.9 : The Seasonal Wind Rose of 2014-2018 in Dilovası.

The results of the monthly wind rose analysis are shown in Figure 2.10. What stands out in this figure is the prevailing wind from the northeast is especially clear between July and November. In addition, the winds from southwest and northeast directions are seen as proportional between January and April. The monthly average wind speed is placed on the bottom right of each plot. According to this, the maximum wind speed value is seen in August, whereas the minimum wind speed value is seen in December. Also, the maximum percentage of prevailing wind direction is seen in August.

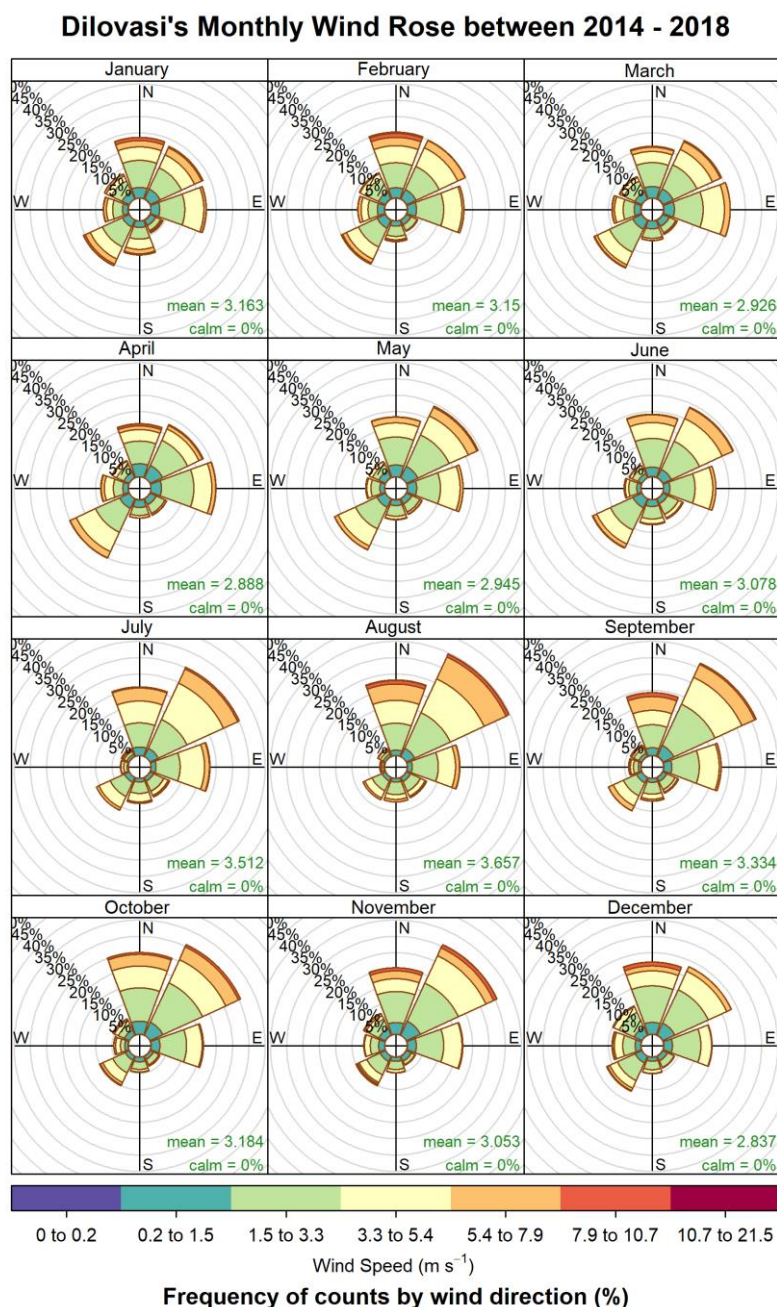


Figure 2.10 : The Monthly Wind Rose of 2014-2018 in Dilovasi.

2.2 Data and Methodology

2.2.1 Data

Meteorological data used for Kocaeli-Dilovası in this study is obtained from the Turkish State Meteorological Service (TSMS, 2021). In Dilovası district, there is only one meteorological station classified as AWOS and it has station number 18411. The coordinates of the meteorological station are 40°46'52.0"N 29°34'22.1"E. The location of the meteorological station and in Dilovası is shown as blue one in Figure 2.11.

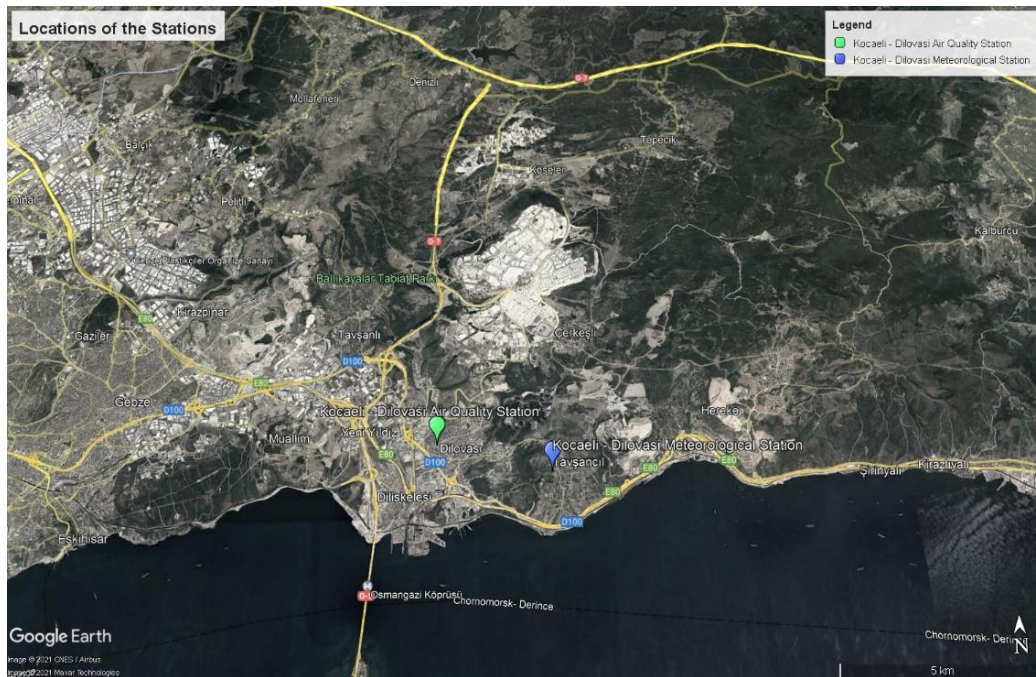


Figure 2.11 : The Observation Stations in Dilovası (Google Earth, 2021).

Data used in the previous section named “2.1 Study Area” is analysed for climate purposes. The analysis is made with hourly wind speed and direction, temperature and rainfall data between 2014- 2018. The analysis is made to be an example for long term climate data in Dilovası. Due to being a district after 2008, the meteorological station in Dilovası is thought to be installed later than the stations in other districts in Kocaeli. The available data percentages are %91, %86 and %89 for rainfall, wind speed and direction and temperature data respectively for 5-year data. In addition to that, only wind speed and direction data for 2018 are used for Wind Speed and Direction ITS scenario.

Pollutant data used in this study is obtained from the Ministry of Environment and Urbanization's National Air Quality Monitoring Network (MoEU,2021). Although there are active 3 air quality stations in Dilovası, only the Kocaeli-Dilovası station is selected due to the presence of PM₁₀, NO₂ and CO pollutant data together. The coordinates of the air quality station are 40°47'19.3"N 29°32'13.6"E. The location of the Kocaeli-Dilovası air quality station is shown by the green dot in Figure 2.11. The pollutant data covers hourly PM₁₀, NO₂ and CO pollutant data in 2018 and it was used for AQI ITS scenario's decision stage. Moreover, it's important to emphasise that only PM₁₀ pollutant data was used for BenMAP-CE's socio-economic calculations.

2.2.2 Methodology

The methodology of this thesis covers the use of one atmospheric chemical model, one statistical software and one health impact assessment program in brief. Before the analysis part, the data quality control stage is applied for all meteorological and air pollutant datasets. In the first stage of this thesis, the meteorological and air quality analyses are made to create the algorithm of ITS scenarios' decision stage. The prevailing wind direction is decided by the analysis and also it is found the days which exceeded the pollutant limit values for both scenarios. Most of the statistical analysis and the related figures are made by openair package via R Software (Carslaw & Ropkins, 2012; R Core Team, 2021). Since the second stage is related to creating a new hourly pollutant dataset, the WRF-Chem model was run for this purpose. The meteorological data and the emission data were needed to run WRF-Chem, the input meteorological data were provided by GDAS model output (NCEP, 2015) and the emission data were provided by EDGAR-HTAP and GOCART database. WRF-Chem model was run for one year as 2018 and the gridded pollutant output as hourly data from the model was prepared for BenMAP-CE. Then, in the next stage, two different hourly pollutant datasets from the model and the air quality station were converted to daily pollutant datasets separately to use as input for BenMAP-CE. In the last stage, data setup was completed for BenMAP-CE and the program was run with the recovery percentage for two scenarios to evaluate the socio-economic effects (Sacks et al., 2018).

2.3 WRF-Chem Model

WRF-Chem model is one of the best-known atmospheric chemistry models, the model is used for simulating emissions, transportation and chemical transformation of aerosols. WRF-Chem can be thought of as the chemistry package of the WRF (Weather Research and Forecasting) model (Grell et al., 2005). The model is an online model which allows the two-sided feedbacks between meteorology and chemistry parts such as aerosol direct and indirect radiative forcing (Fast et al., 2006). The model is also a regional model and the investigation of air quality on a regional scale is one of the main purposes of the model.

2.3.1 WRF-Chem Mechanism

In Figure 2.12, the flow chart of the WRF-Chem model is shown. The WRF-Chem model has three main stages as the WRF model itself. These stages are called WRF Pre-processing (WPS), WRF-ARW and Post-processing.

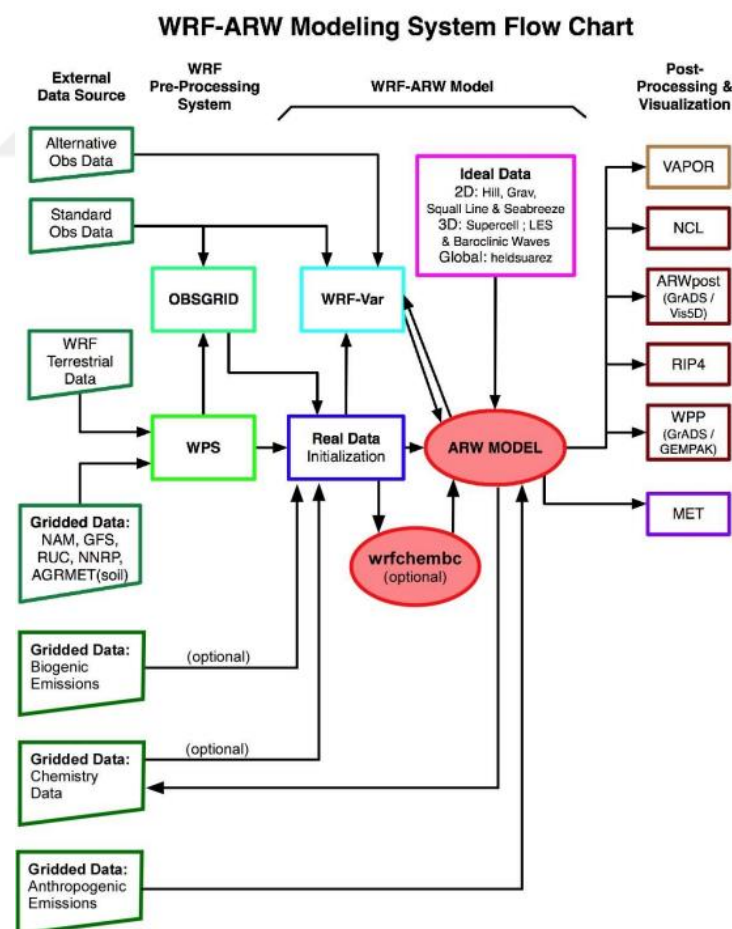


Figure 2.12 : The Flow Chart of WRF-Chem Model (NCAR, 2021).

WPS is the stage where the meteorological data, terrestrial data and emissions data are obtained from external data sources and these datasets are processed so that they can be used as input data in the next stage. On WPS, the user also determines the model domain, resolution, time interval and other initial boundary conditions. On the WRF-ARW stage, the model simulation is created with the right equations of atmospheric dynamical, physical and chemical processes according to initial & boundary conditions and input datasets by the numerical integration of these input datasets. Lastly, the model output from WRF-Chem is visualized with help of other visualization tools like VAPOR, NCL and ARW-POST on the post-processing (Peckham et al., 2018).

In this study, the 4.3 version of the WRF model was used for modelling the city of Kocaeli including the Dilovası district. There are no visualization tools used due to using model output as numerical data for BenMAP-CE. There is only one domain covering Dilovası and the nearest districts. The domain used in the model is shown in Figure 2.13. The domain's horizontal resolution is 4 km x 4 km. The time interval of model operation is from 01-01-2018 to 31-12-2018.

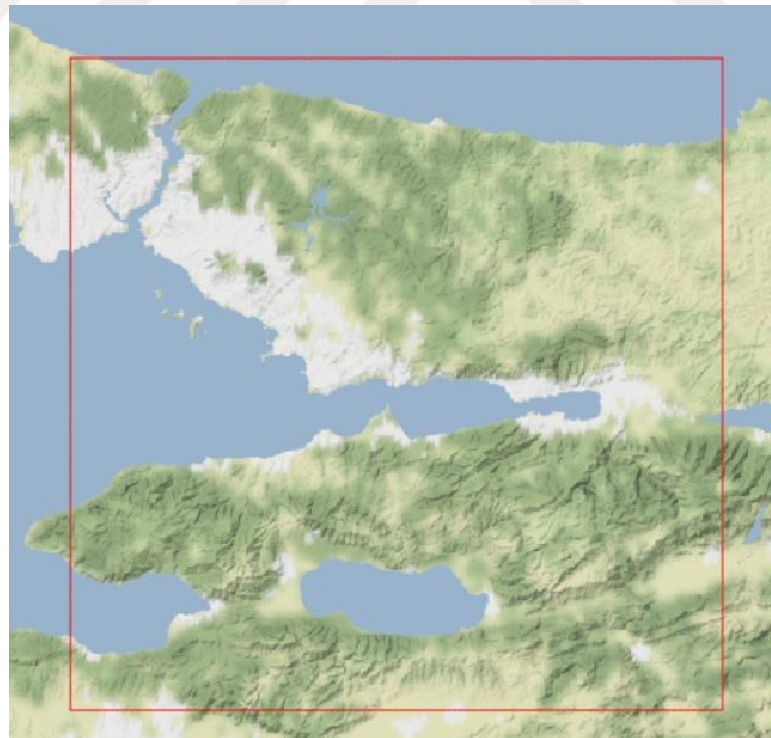


Figure 2.13 : The Domain used in WRF-Chem Model.

2.3.2 WRF-Chem Input Datasets

The meteorological input dataset was obtained from GDAS model output which has 0.25° resolution, and it equals approximately 25 km according to Turkey's latitudinal location. Since GDAS is known to be a global model, it is needed to increase horizontal resolution with the WRF model which is a regional model to get more qualified model results. GDAS model output was chosen to be obtained as meteorological input because it has so many types of observational data such as surface, balloon and satellite observational data. The data format of GDAS is gridded binary (GRIB) and it can be used as the input to start models (NCEI, 2018).

The other dataset from an external source is emission data for WRF-Chem. There are anthropogenic and biogenic emission gridded data used for WRF-Chem. Since the anthropogenic emissions are more responsible than biogenic emissions in Dilovası, only gridded anthropogenic emission data was used as input. Moreover, these types of gridded data were prepared with a pre-processor tool called PREP-CHEM-SRC (Freitas et al., 2011). This pre-processor tool helps to prepare emission fields of aerosols for use in atmospheric-chemistry models like WRF-Chem. In this thesis, this tool was used with EDGAR-HTAP emission inventory only. In addition to this, if the user wants to use background emissions such as GOCART emissions, the use of GOCART can be managed with chemistry options.

EDGAR-HTAP is a comprehensive global emissions inventory study created by the European Union. While developing this version, a blended database used for global and regional models between 2008 and 2010 was used and covers all countries around the world. There are 9 different emission source types such as air, land and sea transportation emission source, industrial emission source, agricultural emission source (Janssens-Maenhout et al., 2012). The main emission source types used for the Dilovası region are agricultural, industrial and transportation sources. Emission inventory contains many pollutant information such as CH_4 , CO , SO_2 , NO_x , NH_3 , PM_{10} , $\text{PM}_{2.5}$. The emission inventory version used for the study is HTAP_v2 and the inventory data resolution is 0.1×0.1 degrees for gridded maps.

GOCART model emissions, which stands for The Goddard Chemistry Aerosol Radiation and Transport, represent the emissions in the background. The GOCART model is a chemical transport model and is often used to generate simulations on

organic carbon, black carbon and SO₂ emissions. The model includes anthropogenic and natural origin emissions, vertical and horizontal transport of emissions, wet and dry deposition, chemical formation and change processes. While the emission data in the model is used in the PREP-Chem process, it is also included in the chemistry settings of the WRF model to use the chemical process information in the model. Emission data-enhanced resolution is 0.1 x 0.1 degrees for gridded maps.

2.3.3 WRF-Chem Physics & Chemistry Options

There are plenty of physics and chemistry schemes for the options in the model. Most of the schemes are composed according to atmospheric physics equations. The physics and chemistry options used in the model is presented in Table. In addition to these options, 34 vertical levels are selected for the simulation. The first seven options in Table 2.2 belong to the physics suite of the model, the others are in chemistry options.

Table 2.2 : Physics and Chemistry Options used in WRF-Chem.

Physics and Chemistry Options	Schemes
Microphysics	Thompson (Thompson et al. 2008)
Cumulus	Kain–Fritsch (Kain, 2004)
Longwave Radiation	RRTMG Longwave (Iacono et al., 2008)
Shortwave Radiation	Dudhia Shortwave (Dudhia, 1989)
Planetary Boundary-Layer	YSU (Hong et al, 2006)
Surface Layer	MM5 Similarity (Fairall et al., 2003)
Land Surface	Unified Noah Land Surface Model (Tewari et al, 2004)
Chemistry	GOCART coupled with RACM- KPP
Photolysis	Madronich photolysis (TUV)
Emissions	GOCART RACM_KPP Emissions

2.4 Intelligent Transportation System Scenario

In this section, the flow charts of the two ITS scenarios created to reduce air pollution in Dilovası, and the variable and fixed data given as input to the flow charts will be discussed.

One of the studies carried out within the scope of the TÜBİTAK project is the suggestion of an alternative route to be guided and the drawing of it (Öztürk et al., 2019). The proposed alternative route and the highways passing through Dilovası are given in Figure 2.14 and Figure 2.15 below, respectively. The alternative route is for the TEM (E-80) highway and this is because the emission values of the D-100 and E-80 highways are much higher than the D-100 when the emission values of the TEM highway are compared (Arslantaş, 2019).



Figure 2.14 : The Highways through Dilovası (Arslantaş, 2019).



Figure 2.15 : The Alternative Route Design for Dilovası (Öztürk, 2019).

2.4.1 ITS Algorithms and Input Data

A routing algorithm according to air quality indices was created for this first scenario. This scenario is called AQI ITS in this thesis. To increase the air quality in the Dilovası

district, it is aimed to direct the drivers from the existing route to the proposed alternative route, as a result of reaching the AQI values determined by the measured air pollution values at the air quality station. The flow chart of the algorithm is shown in Figure 2.16.

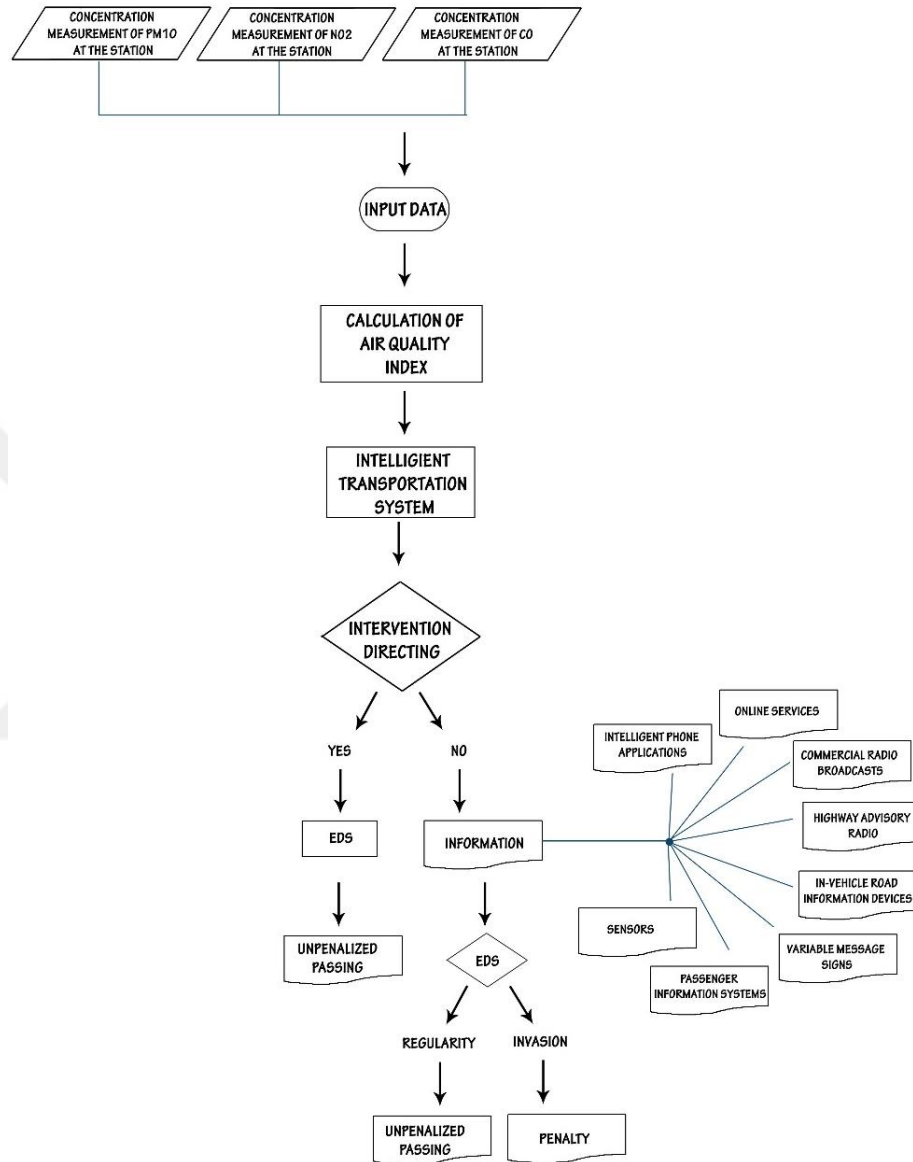


Figure 2.16 : The Flow Chart of Algorithm of AQI ITS Scenario.

To route the drivers, pollutant (PM_{10} , NO_2 and CO) data obtained from air quality measurement stations will be taken in the first place. It was planned to use hourly measurement data from Kocaeli-Dilovası station between 1 January 2018 and 31 December 2018 for the exemplifying of the algorithm system in 2018.

After measurement data are given to the system as input, the AQI values of the pollutant data will be calculated and among the AQI values. After the AQI calculations

are made, the value with the highest AQI value will be taken and given as the maximum AQI value of the environment the value will be selected as in the representation describing the stage in Figure 2.17.

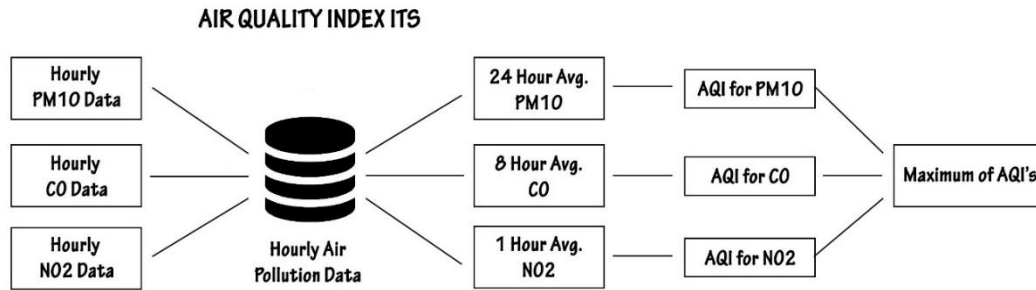


Figure 2.17 : The Calculation of AQI for each pollutant.

It is given in Table 2.3 that will be calculated over the means for each variable. (Kocaeli Provincial Directorate of Environment and Urbanization, 2019).

Table 2.3 : The Air Quality Index Break Points for Pollutants.

INDEX	AQI	SO ₂ (µg/m ³)	NO ₂ (µg/m ³)	CO (µg/m ³)	O ₃ (µg/m ³)	PM ₁₀ (µg/m ³)
		1 Hour Avg.	1 Hour Avg.	8 Hour Avg.	8 Hour Avg.	24 Hour Avg.
Good	0 - 50	0 - 100	0 - 100	0 - 5500	0 - 120	0 - 50
Moderate	51 - 100	101 - 250	101 - 200	5501 - 10000	121 - 160	51 - 100
Sensitive	101 - 150	251-500	201 - 500	10001 - 16000	161 - 180	101 - 260
Unhealthy	151 - 200	501 - 800	501 - 1000	16001 - 24000	181 - 240	261 - 400
Very Unhealthy	201 - 300	851 - 1100	1001 - 2000	24001 - 32000	241 - 700	401 - 520
Hazardous	301 - 500	> 1101	> 2001	> 32001	> 701	> 521

According to the maximum AQI value determined in the light of this information, the system will direct the current route to an alternative route or will not make any direction on the current route. In line with these decisions, the system may direct the drivers from the current route to an alternative route or may not interfere with them at all. During the intervention, driver behaviour will be monitored by Electronic Supervision System (EDS). Drivers will be able to pass without penalty if no direction is made from the existing route to the alternative route. Drivers who do not comply and do not change their route despite the information that the current route will be directed to an alternative route in line with the decisions taken by the system will be subject to penal sanctions through EDS.

On the other routing algorithm, the wind speed and direction data are needed as input data to ITS as in Figure 2.18. The second scenario was determined based on the wind speed and wind direction in Kocaeli - Dilovası station in 2018.

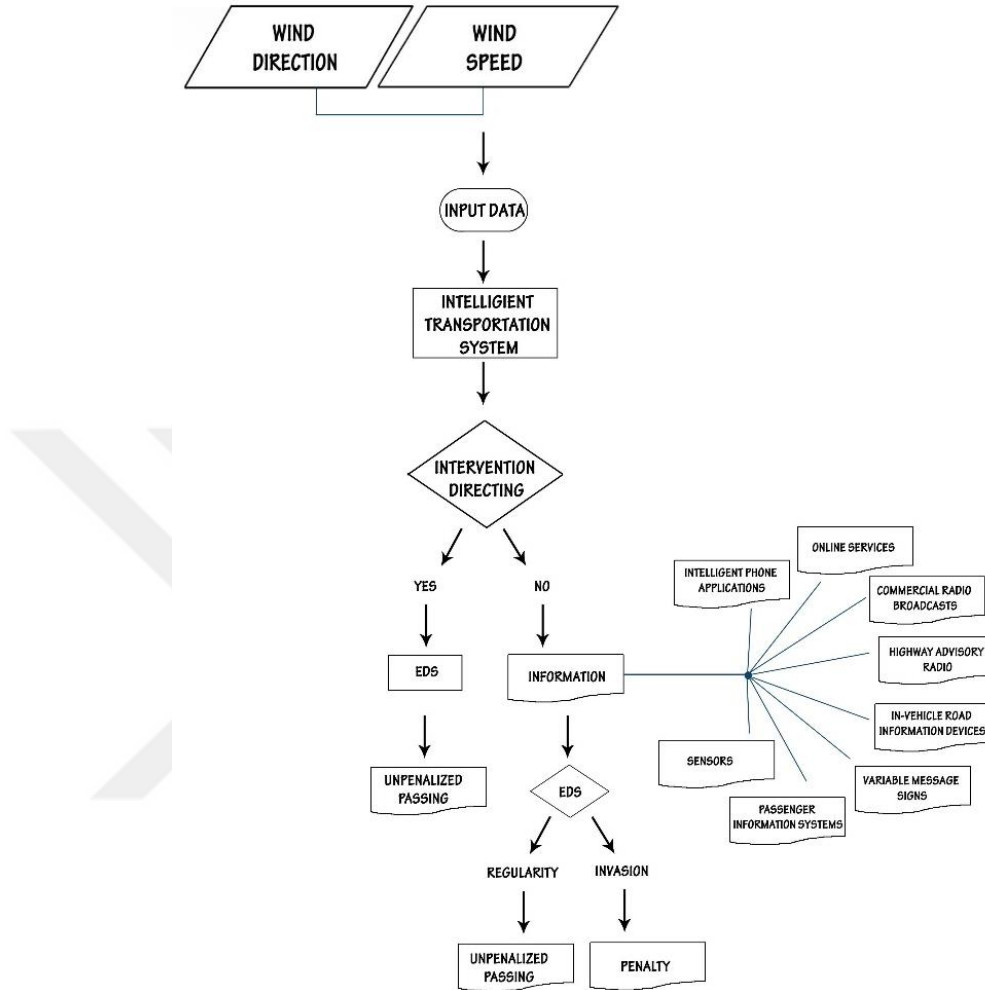


Figure 2.18 : The Flow Chart of Algorithm of WSD ITS Scenario.

In this scenario, the data to be given as input to the smart transportation system are determined as wind speed and direction. A redirection diagram for wind speed and direction is given in Table. These data will be transferred to the smart transportation system and intervention directions will be made or not. For wind direction orientation, the prevailing wind direction, secondary wind direction and tertiary wind direction are divided into two groups as one group and all other wind directions as a group. For guidance based on wind speed, wind speeds are 0- 0.2 m/sec, 0.3- 1.5 m/sec, 1.6- 3.3 m/sec, 3.4- 5.4 m/sec, 5.5- 7.9 m/sec, 8.0-10.7 m/sec. divided into six groups. While grouping for wind speed, Beaufort Scale was taken as a basis (WMO, 1970).

When the 'NO' option is encountered in Table 2.4, no intervention for redirection is planned. If it is decided on intervention, passengers will be informed and directed to EDS with the information methods in the ITS flowchart specified in the Figure 2.18. During the intervention, driver behaviour will be monitored by EDS. Penal sanctions will be applied through EDS to drivers who do not behave in line with the decisions taken by the system.

Table 2.4 : The Decision Table for Redirection According to Wind.

Wind Speed / Wind Direction	0-0,2 m/sn	0.3-1.5 m/sn	1.6-3.3 m/sn	3.4 - 5.4 m/sn	5.5 - 7.9 m/sn	8.0 - 10.7 m/sn
Prevailing Wind Direction (inc. 2 nd and 3 rd)	NO DIRECTING TO ALTERNATIVE ROUTE					
Other Wind Direction	NO	YES	YES	YES	YES	YES

2.5 BenMAP-CE Program

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2.5.1 BenMAP-CE Process

BenMAP-CE is a health benefits assessment program that stands for The Environmental Benefits Mapping and Analysis Program—Community Edition. The program was first developed in 2003 as an open-source tool by U.S EPA and has continued to be developed as a program ever since (Sacks et al., 2018). The program answers two main questions: 1. What are the impacts of improving air quality on public health and socio-economic benefits? 2. How much health burden can be associated with total air pollution levels? Therefore, it can be said that this program predicts the human health impact and economic value of air quality improvement (U.S EPA, 2021). Estimating human health effects is made with a function called Health Impact Function (HIF) in the program. HIFs are derived from epidemiological literature and these

functions are made for the relationship between the pollutant concentrations and certain health outcomes (death, hospital admissions, illnesses). The derivation of HIF from the literature is presented in Figure 2.19.

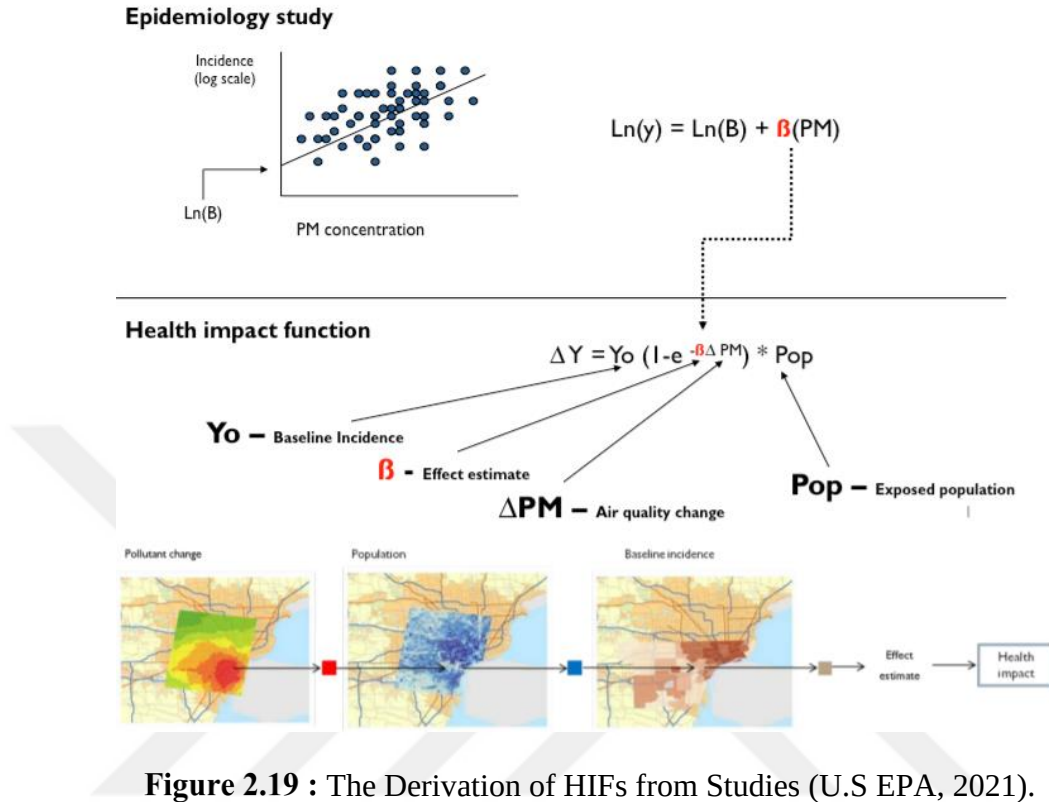


Figure 2.19 : The Derivation of HIFs from Studies (U.S EPA, 2021).

The normal case rate of the first equation in the Figure 2.19 is $\ln(B)$ which is accepted as constant. The relationship between the incident and the pollutant density is expressed as β (correlation coefficient) and can take many values depending on the region, pollutant and impact rate. This β value is calculated to be used in the second equation in Figure 2.19. The components in HIF can be explained in the following sentence. ΔY represents the estimated health impact attributed to air pollution; Y_0 represents the base case incidence rate; β value is the proportion of the population that will be affected by the air pollution change; ΔPM represents the change in air quality; Pop represents the affected population by air pollution. Simply the health effect equals the product of the value of air quality change, the value of health effect estimation, the value of exposed population and the value of health baseline incidence. Similarly, the economic value is calculated with the product of health effect and the cost of health effect which is shown in Figure 2.20. For example, the avoided death cases are calculated by Value of Statistical Life (VSL) in this study. On the other hand, the economic valuation data is used for the cost of other health effects. BenMAP-CE's

results may vary as health data categories (bronchitis, asthma, lung cancer, diabetes, etc.), health impact functions, and air pollutant data increase, but the most commonly used pollutants to monitor the effects of air pollutants are ozone and particulate matter.

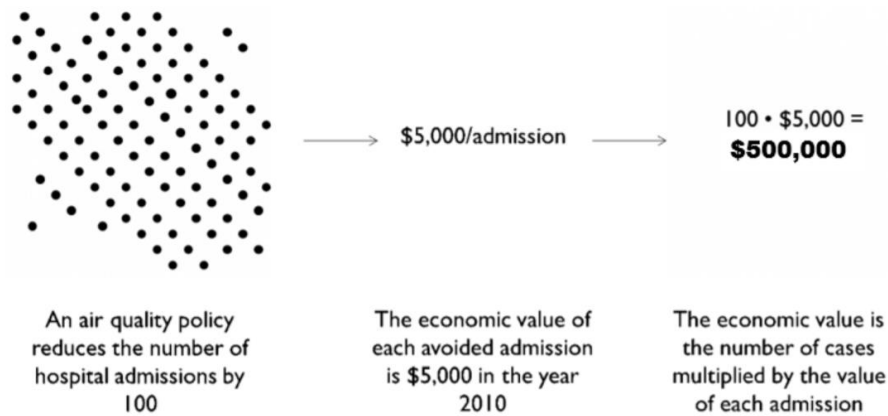


Figure 2.20 : The Calculation of Economic Value (U.S EPA, 2021).

There is a GIS tool in the program which allows the user to create, visualize the distribution of air pollution, population, incidence rates and other types of data. The GIS example of Kocaeli used in this study is presented in Figure 2.21.

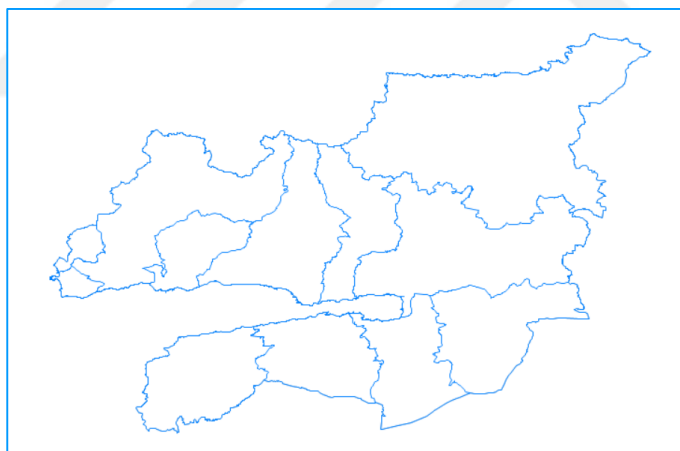


Figure 2.21 : The GIS map of Kocaeli.

Input datasets of the BenMAP-CE program can be listed as air pollution concentration data population data, national, regional and health incidence data, HIF or C-R data from epidemiological studies. Figure 2.22 provides the framework of the program with inputs and outputs.

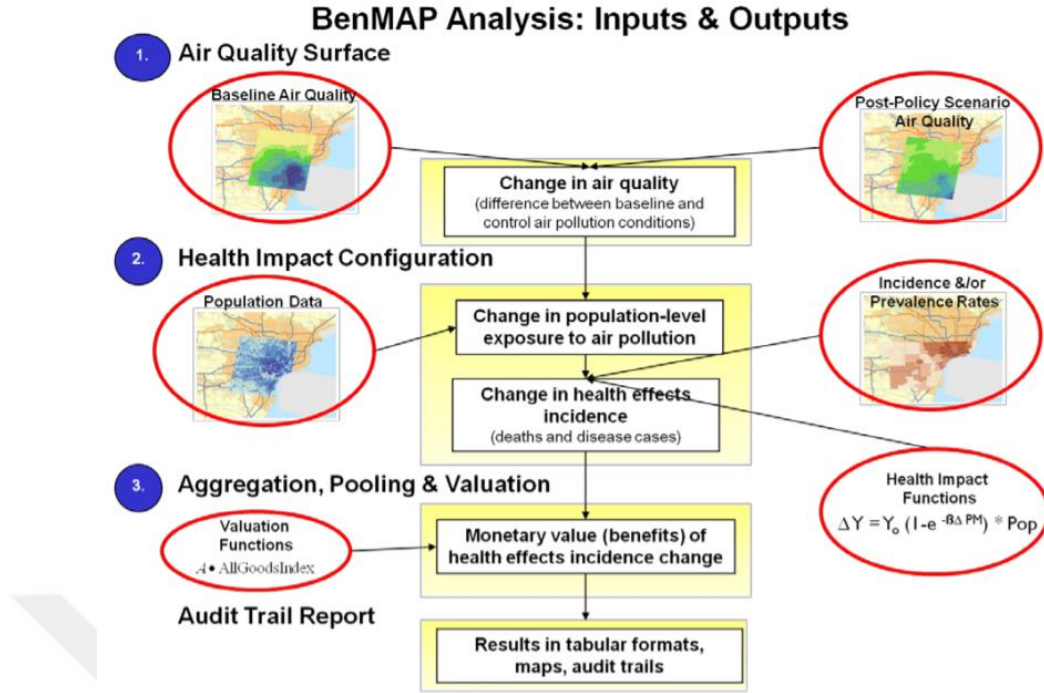


Figure 2.22 : BenMAP-CE Processes with Inputs and Outputs (U.S EPA, 2021).

2.5.2 BenMAP-CE Input Datasets

In this section, the datasets used for the program for this thesis will be introduced. In the BenMAP-CE study, 2018 was chosen as the sample year for the scenario analysis. Data from 12 districts, especially Dilovası, were used. The two main reasons for using the data of other districts together in addition to the Dilovası district are the pollution rose analysis, it is seen that the air quality of the surrounding districts affects the air quality of the Dilovası region and that the geographical data integrity of Dilovası and other districts must be ensured for a successful pollution distribution in the BenMAP-CE program.

Firstly, The air pollution data is obtained from measurement data from the air quality stations and also gridded WRF-Chem model outputs. The first dataset introduced will be measurement data. Air pollution measurements are made every hour at all air quality monitoring stations throughout Turkey, and the results are published online on the National Air Quality Monitoring Network (MoEU, 2021). The data of the previous years' measurement results can be accessed from this network. Concentration values of pollutants are usually reported in units of $\mu\text{g}/\text{m}^3$. Information about the air quality stations in Kocaeli is given in the Table. In the selection of air pollution data, a two-stage selection process was carried out as station selection and pollutant selection,

respectively. While choosing these stations among the stations, it was taken into consideration that at least 1 station was selected from all the districts of Kocaeli with air quality stations. In the selection of PM₁₀ pollutants, attention was paid to the pollutant measured in all of the selected air quality stations and the availability of data on the pollutant at the stations (no missing data). The measurement datasets from these stations are hourly data from 01-01-2018 to 31-12-2018 and they were brought into the data format that BenMAP-CE needs by taking the 24-hour averages of the hourly data.

Table 2.5 : The Air Quality Stations used for this study.

Station No.	Station Name	Location	Available Parameters
1	Kocaeli	40.7655 N, 29.9511 E	NO,NO ₂ ,NO _x ,PM ₁₀ , PM _{2.5} ,SO ₂ , O ₃
2	Kocaeli-Alikahya MHTM	40.7708 N, 30.0075 E	NO NO ₂ ,NO _x , PM ₁₀ ,SO ₂
3	Kocaeli- Dilovası	40.7886 N, 29.5369 E	PM ₁₀ , NO, NO ₂ , NO _x , SO ₂ , O ₃ , CO
4	Kocaeli-Gebze MTHM	40.8111 N, 29.4363 E	PM ₁₀ , NO, NO ₂ , NO _x , SO ₂ , O ₃ , As, o-Ksilen, CH ₄ , NMHC, Benzen, Ni, Pb, Ksilen, PAH-BAP, HC, CO, Cd, m-Ksilen, p-Ksilen, Toluene, Hg, Etilbenzen
5	Kocaeli-Gölcük MTHM	40.7259 N,29.7946 E	CO, NO, NO ₂ , NO _x , PM _{2.5} , PM ₁₀ , SO ₂ , O ₃
6	Kocaeli-İzmit MTHM	40.7681 N,29.9381 E	CO, NO, NO ₂ , NO _x , PM ₁₀
7	Kocaeli-Kandıra MTHM	41.1307 N,30.0065 E	NO, NO ₂ , NO _x , PM _{2.5} , PM ₁₀ , O ₃
8	Kocaeli-Körfez MTHM	40.746 N, 29.7888 E	CO, PM _{2.5} , PM ₁₀ , NO, NO ₂ , NO _x , SO ₂ , O ₃
9	Kocaeli-Yeniköy MHTM	41.1307 N, 30.0065 E	NO, NO ₂ , NO _x , PM ₁₀ , SO ₂ , O ₃

As it can be seen from Table 2.5, nine air quality stations are selected in twelve districts. Kocaeli and Kocaeli-İzmit stations are both located in the İzmit district, therefore PM₁₀ measurements from eight districts could be used as an input. WRF-Chem model outputs were used to complete the missing datasets from Darica, Derince, Karamürsel and Çayirova districts as an alternative approach. In total, gridded pollutant concentration data were obtained for twelve districts. The gridded outputs were selected as the nearest grid to the selected measurement station's locations shown in Table 2.6. The gridded datasets obtained from the model were in the form of hourly data between 01-01-2018 and 31-12-2018 and they were brought into the data format that BenMAP-CE needs by taking the 24-hour averages of the hourly data like measurement data.

Table 2.6 : The Location Information used for gridded WRF-Chem output.

Station No.	District Name	Location
1	Kocaeli	40.7655 N, 29.9511 E
2	Kocaeli-Alikahya	40.7708 N, 30.0075 E
3	Kocaeli- Dilovası	40.7886 N, 29.5369 E
4	Kocaeli-Gebze	40.8111 N, 29.4363 E
5	Kocaeli-Gölcük MTHM	40.7259 N,29.7946 E
6	Kocaeli-İzmit	40.7681 N,29.9381 E
7	Kocaeli-Kandıra MTHM	41.1307 N,30.0065 E
8	Kocaeli-Körfez	40.746 N, 29.7888 E
9	Kocaeli-Yeniköy	41.1307 N, 30.0065 E
10	Kocaeli-Darica	40.7791 N, 29.3785 E
11	Kocaeli-Derince	40.7644 N, 29.8243 E
12	Kocaeli- Karamursel	40.6905 N, 29.5972 E
13	Kocaeli-Cayirova	40.8325 N, 29.3867 E

The second dataset covers the population and death data from TURKSTAT. The population of Kocaeli province in 2018 is 1,883,000. The most crowded districts are Gebze, İzmit and Darica among the 12 districts in Kocaeli respectively. As it was told in previous chapters, all data used in BenMAP-CE should belong to 2018 for data integrity and accurate results.

It is extremely important to provide population and mortality data, which are used as inputs for the health cost calculations of the BenMAP-CE program. Population data were obtained from the Turkish Statistical Institute by district, gender and age range (TURKSTAT, 2021).

The program can use population data categorized separately as districts, age ranges, gender, race and origin. For example, the total number of female populations aged 30 to 34 in Darica district, regardless of race and origin, should be entered as 9563. Population data was available for each district of Kocaeli, separately for male and female groups, divided into a total of 38 groups, 19 years of age. The population data of 2018 and the sample input data order are given in Table 2.7.

Table 2.7 : The Sample Dataset processed in BenMAP-CE.

District Name	District No.	Population	Race	Ethnicity	Age Range
Başıskele	7	97.817	ALL	ALL	0TO4
Çayırova	8	129.655	ALL	ALL	5TO9
Darica	9	201.468	ALL	ALL	10TO14
Derince	6	140.982	ALL	ALL	15TO19
Dilovası	10	47.948	ALL	ALL	20TO24
Gebze	1	371.000	ALL	ALL	25TO29
Gölcük	2	162.584	ALL	ALL	30TO34
İzmit	11	363.416	ALL	ALL	35TO39
Kandıra	3	51.348	ALL	ALL	40TO44
Karamürsel	4	56.604	ALL	ALL	45TO49
Kartepe	12	118.066	ALL	ALL	50TO54
Körfez	5	115.503	ALL	ALL	55TO59
					60TO64
					65TO69
					70TO74
					75TO79
					80TO84
					85TO89
					90UP

There is no separate data for race and origin groups because there is only gender and age grouping in the population data obtained from TURKSTAT, but it didn't create a problem for the calculation to be made for Dilovası and other districts of Kocaeli. The age range starts from zero and increases by four and ends in the 90 and over the group. Looking at the BenMAP-CE samples run for other countries, it was seen that this data was more detailed and sufficient.

The death caused by respiratory and cardiovascular diseases, which is the most common causes of death due to air pollution should be used for the mortality data. The data of mortality incidence rate caused by cardiovascular and respiratory diseases couldn't be obtained for Kocaeli and its districts. The reason why these data are needed is the calculation that the program will make in line with the Health Impact Function. In this sense, data on the total number of deaths were obtained from TURKSTAT. However, detailed mortality data are not available in TURKSTAT. As an alternative approach, the all-cause mortality data from TURKSTAT and the death incidence rate caused by cardiovascular and respiratory diseases cases BenMAP-CE's training material for Santiago, Chile. The following equations were used to determine

mortality incidence rates for both respiratory and cardiovascular diseases in equation (2.1) and equation (2.2).

$$\frac{\text{Mortality Incidence Rate by Respiratory Diseases (Santiago)}}{\text{Total Number of Death Cases (Santiago)}} = \frac{\text{Mortality Incidence Rate by Respiratory Diseases (Kocaeli)}}{\text{Total Number of Death Cases (Kocaeli)}} \quad (2.1)$$

$$\frac{\text{Mortality Incidence Rate by Cardiovascular Diseases (Santiago)}}{\text{Total Number of Death Cases (Santiago)}} = \frac{\text{Mortality Incidence Rate by Cardiovascular Diseases (Kocaeli)}}{\text{Total Number of Death Cases (Kocaeli)}} \quad (2.2)$$

Data related to HIF used for PM₁₀ pollutant in the program is obtained from Wong et al.'s study about the short-term effects of air pollution on mortality for four Asian cities. (Wong et al.,2008). In this study, Wong et al. obtained the C-R (concentration-response) function, excess risk (%) of mortality and for PM₁₀, ozone, sulphur dioxide and nitrogen dioxide. The reason for use of this HIF derived from Wong et al.'s study is being one of the recommended HIF by U.S EPA and there is no detailed study for Turkey.

Lastly, the most needed data when calculating health costs is economic valuation data. The equations that are required to be given as input to the program are shown as equation (2.3). VSL (Value of Statistical Life) stands for statistically the value of human life, the local exchange rate between the risk of mortality and money (U.S EPA, 2021). In Equation (2.3), $VSL_{Turkey,2018}$ represents the VSL value for Turkey in 2018 Turkish Lira at 2018 Turkey income levels. $VSL_{USA,1990}$ is the VSL value for the US in 1990 US dollars at 1990 US income levels. Y is the per capita GDP of the specified country in the specified year, expressed in constant international (PPP-adjusted) dollars and PPP_{1990} is the Purchasing Power Parity index in 1990 in units of Turkish Lira per international dollar. CPI_{Turkey} represents the consumer price index in Turkey in the specified year. ε , the income elasticity of the VSL, means the same for income adjustments across countries (ε_1) and over time (ε_2). In addition, Equation (2.3) should

simply to Equation (2.4) below by using only ε with the default value (0.4) of BenMAP-CE.

$$\begin{aligned} VSL_{\text{Turkey, 2018}} = VSL_{\text{USA,1990}} * \left(\frac{Y_{\text{Turkey,1990}}}{Y_{\text{USA,1990}}} \right)^{\varepsilon_1} * \\ \left(\frac{Y_{\text{Turkey,2018}}}{Y_{\text{Turkey,1990}}} \right)^{\varepsilon_2} * PPP_{1990} * \frac{CPI_{\text{Turkey,2015}}}{CPI_{\text{Turkey,1990}}} \end{aligned} \quad (2.3)$$

$$\begin{aligned} VSL_{\text{Turkey, 2018}} = VSL_{\text{USA,1990}} * \left(\frac{Y_{\text{Turkey,2018}}}{Y_{\text{USA,1990}}} \right)^{\varepsilon} * \\ PPP_{1990} * \frac{CPI_{\text{Turkey, 2015}}}{CPI_{\text{Turkey, 1990}}} \end{aligned} \quad (2.4)$$

The values in the equations are taken from the World Bank data and OECD and shown in Table 2.8 (Worldbank, 2021; OECD,2021).

Table 2.8 : The Economical Values Used in BenMAP-CE.

COUNTRY	YEAR	VSL (MEAN)	GDP PER CAPITA (CONSTANT 2010 US \$)	PPP (TURKISH LIRA PER INTERNATIONAL \$)	CONSUMER PRICE INDEX (2010 = 100)
United States	1990	\$4,800,000	\$36,312	-	-
Turkey	1990	-	\$6,774	0.001	0.072
	2018	<i>Estimated by equation</i>	\$15,186	1.896	203.5

Table 2.9 : The Value of Parameters in Equation (2.4).

PARAMETER	VALUE
$VSL_{US,1990}$	\$4,800,000
$\left(\frac{Y_{\text{Turkey,2018}}}{Y_{US,1990}} \right)^{\varepsilon}$	0.705
PPP_{1990}	0.001
$\frac{CPI_{\text{Turkey 2018}}}{CPI_{\text{Turkey 1990}}}$	2,826.3

3. INTELLIGENT TRANSPORTATION SYSTEM SCENARIOS FOR AIR POLLUTION REDUCTION

In this section, the socio-economic results of two air pollution reduction scenarios named WSD and AQI will be shared. The socio-economic results include the results of the BenMAP-CE program run with the results of the atmospheric chemical model and measurement data. Also, the performance analysis of the WRF-Chem model for 9 grid points which has air quality measurement data is included. In Table 3.1, root mean square error (RMSE), Pearson correlation coefficient (r), mean bias (MB), the fraction of predictions (FAC2) values are shown for all the stations used in this study. The calculations for these errors and performance indicators are made according to the equations below. All equations have parameters like n (total number of data), i (the time), O_i (observed values), P_i (predicted values), $\bar{P}$ (mean value of prediction) and $\bar{O}$ (mean value of observation). The higher r value indicates the success of prediction according to measurement, likewise, the higher FAC2 value indicates the success of prediction. On the other hand, the lower RMSE value is better for prediction as it indicates the error of prediction. MB value shows underestimation/overestimation of prediction according to measurement values.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}} \quad (3.1)$$

$$r = \frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2 \sum_{i=1}^n (P_i - \bar{P})^2}} \quad (3.2)$$

$$MB = \frac{1}{n} \sum_{i=1}^n (P_i - O_i) \quad (3.3)$$

$$FAC2 = \text{fraction of values } 0.5 \leq \frac{P_i}{O_i} \leq 2.0 \quad (3.4)$$

Table 3.1 : Performance Analysis of WRF-Chem Model Outputs.

Station No.	Station Name	RMSE	r	MB	FAC2
1	Kocaeli	58.58	0.30	-53.03	0.019
2	Kocaeli-Alikahya MHTM	47.00	0.25	-40.95	0.041
3	Kocaeli- Dilovası	48.35	0.56	-41.18	0.063
4	Kocaeli-Gebze MTHM	19.03	0.51	-12.09	0.627
5	Kocaeli-Gölcük MTHM	23.88	0.11	-21.35	0.312
6	Kocaeli-İzmit MTHM	58.40	0.41	-45.98	0.131
7	Kocaeli-Kandıra MTHM	20.47	0.27	-16.51	0.205
8	Kocaeli-Körfez MTHM	39.36	0.44	-34.78	0.136
9	Kocaeli-Yeniköy MHTM	30.20	0.37	-25.22	0.180

The lowest value of RMSE is found in the Kocaeli-Gebze MHTM station and the highest value is found in the Kocaeli station. The highest correlation between model and measurements is observed in the Kocaeli-Dilovası station and the lowest correlation value is observed in the Kocaeli-Gölcük MHTM station. All MB values show that predicted values are underestimated according to measurement data, the biggest MB value is seen in the Kocaeli station and the lowest one is seen in the Kocaeli-Gebze MHTM station. This means the predicted values for the Gebze station is closest to measurement values. The FAC2 values are generally low but again Kocaeli-Gebze MHTM has the highest value and Kocaeli station has the lowest value. If all the metrics are taken into account, the prediction of the Kocaeli-Gebze station is the most successful prediction of all stations.

3.1 Intelligent Transportation System Scenario with Air Quality Index

In this chapter, the calculation of percentage reduction of air pollution needed for BenMAP-CE is explained and the yearly calendar of air quality indices according to pollutants are given. In the last part, the health and economic outcomes from the BenMAP-CE program run with WRF-Chem model output data and air quality measurement data are shared.

3.1.1 Air Quality Index Analysis of Dilovası for 2018

AQI index calendars created with hourly PM₁₀, NO₂ and CO pollutant data of Kocaeli - Dilovası air quality station are given in Figure 3.1, Figure 3.2 and Figure 3.3. Air quality index values of PM₁₀ pollutants are shown in Figure 1. It is seen that the AQI values in the range of 0-50 for 2018 constitute approximately 1/3 of the year. Considering that the air pollution in Dilovası is mainly caused by PM₁₀, it can be said that the AQI calendar here provides a consistent result. Values in the sensitive group of PM₁₀ were mostly seen in January and April. It can be seen that AQI values are not in the group between 0-50 in April.

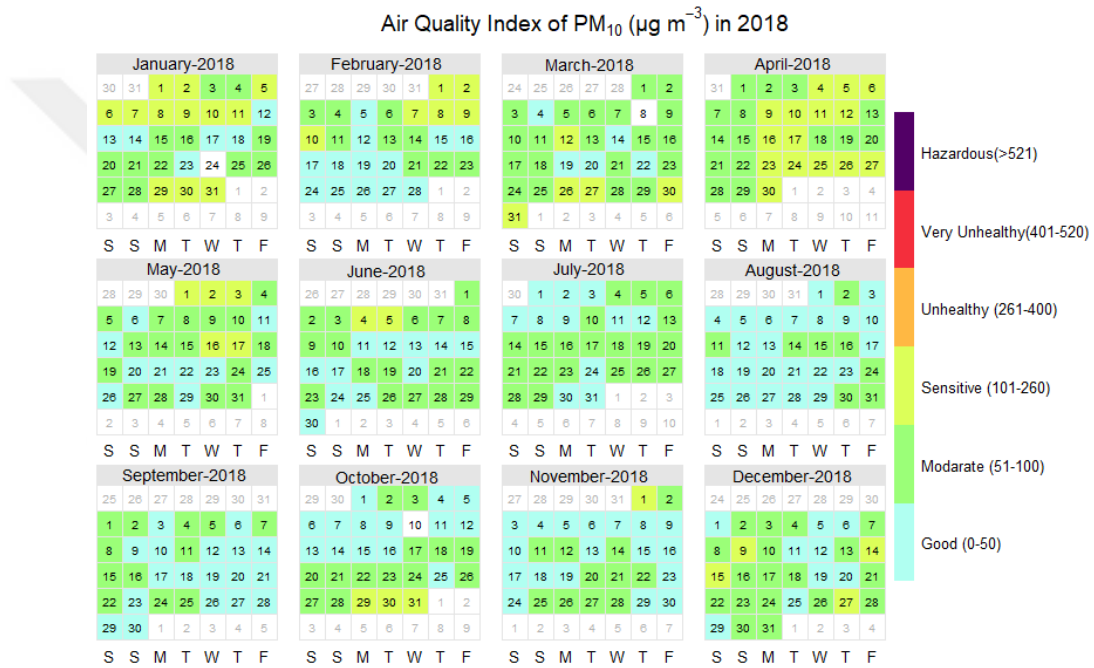


Figure 3.1 : The AQI Calendar of PM₁₀ in 2018.

It has been observed that the number of days in the good category of the NO₂ pollutant is much higher when compared to the PM₁₀ pollutant in the AQI calendar in Figure 3.2. It is seen that the days when AQI values are in the moderate class are distributed between January and April. The presence of moderate and sensitive groups is observed in half of April as seen in Figure 3.2.

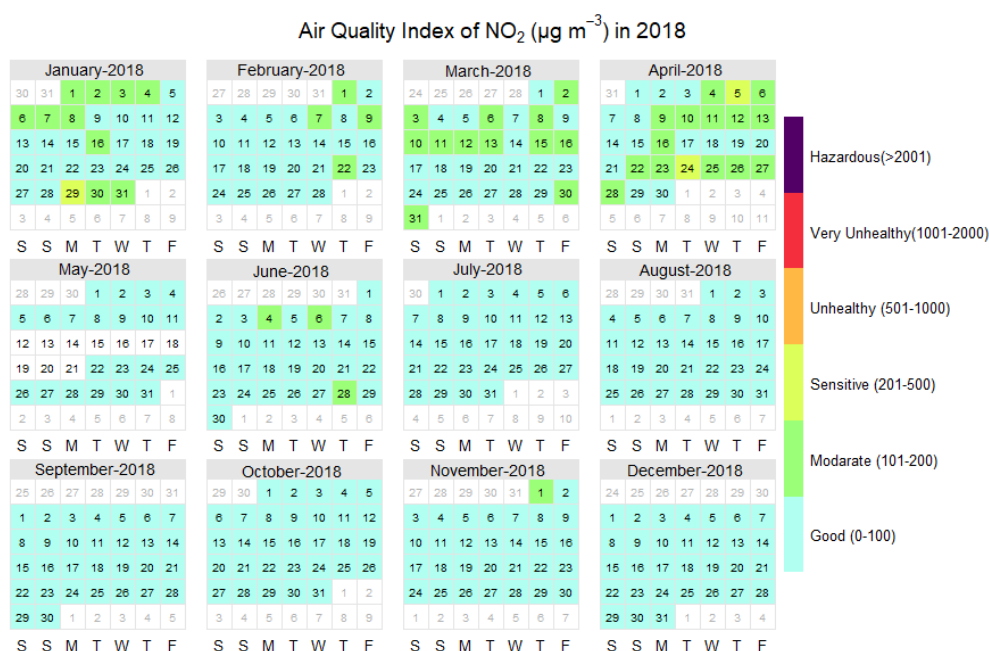


Figure 3.2 : The AQI Calendar of NO₂ in 2018.

As it can be seen in Figure 3.3, AQI values of CO pollutant don't pose a danger to human health. In terms of percentage calculation according to AQI values, CO's contribution is net zero.

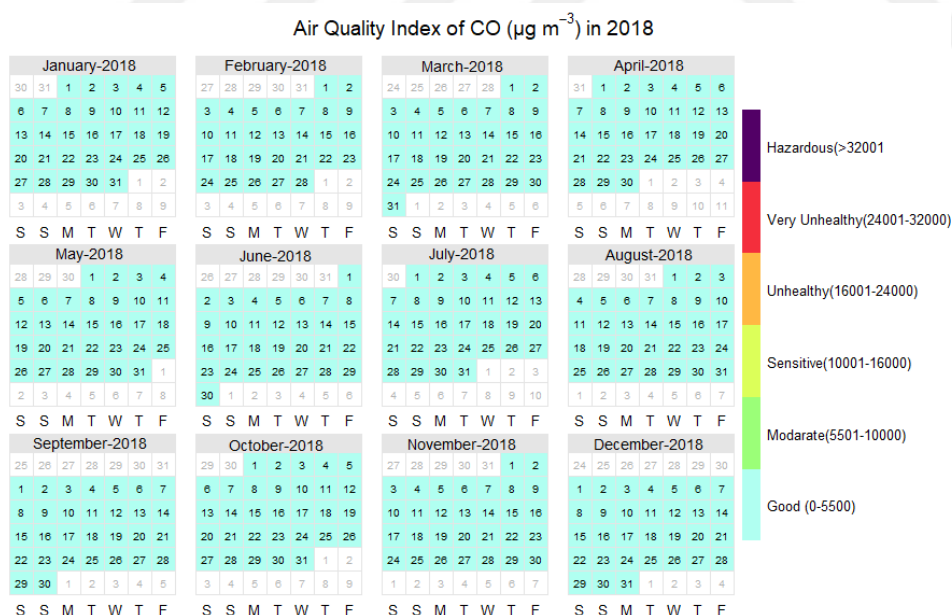


Figure 3.3 : The AQI Calendar of CO in 2018.

In light of this information from AQI calendars, the reduction rate was calculated. The ratio of the days in which the AQI values of the PM₁₀ pollutant exceeded 50 to all days was taken as the days for which guidance was planned. This group includes Moderate

and Sensitive groups. The percentage reduction value was calculated as 64% and this value was used as the reduction percentage in the BenMAP-CE program.

3.1.2 Economic and Health Outputs for AQI ITS Scenario

In Figure 3.4, the air quality change in Kocaeli's Districts according to %64 improvement is shown. Dilovası is one of the most influenced districts by the improvement. Delta represents the change between the reduced concentration values and the baseline concentration values. According to PM₁₀ concentration values, the change in Dilovası is between 31.34 - 35.73 $\mu\text{g}/\text{m}^3$. The prediction for avoidable death cases in every district in Kocaeli is given in Figure 3.5. Unlike the amount of change of PM₁₀ concentrations in Dilovası, the avoidable mortality case are lower than in other districts like Gebze and Izmit. The avoidable mortality case number for Dilovası is less than 19 people for 2018. The reason for this result is thought of as the importance of population density in Health Impact Function.

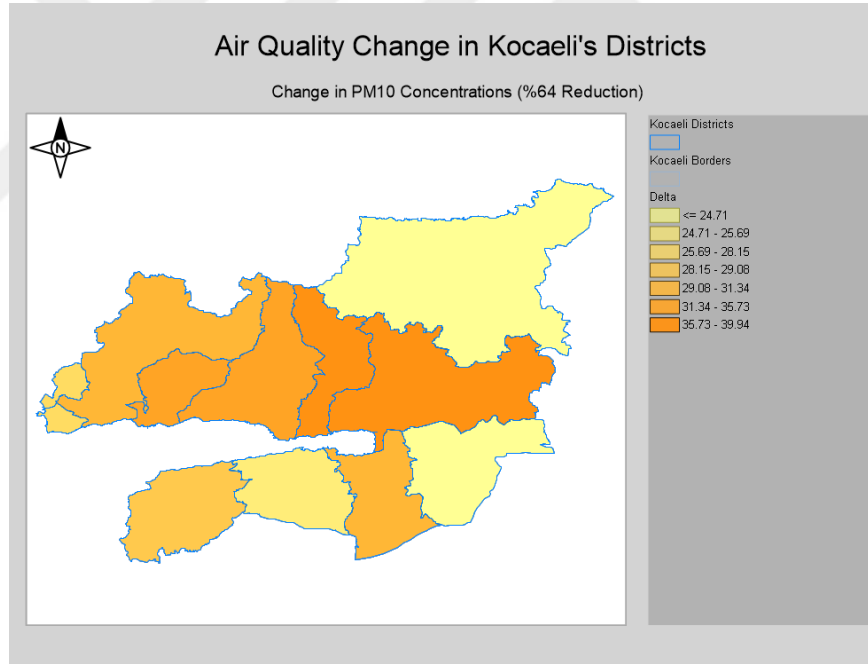


Figure 3.4 : Air Quality Change in Kocaeli (%64 Reduction with OBS).

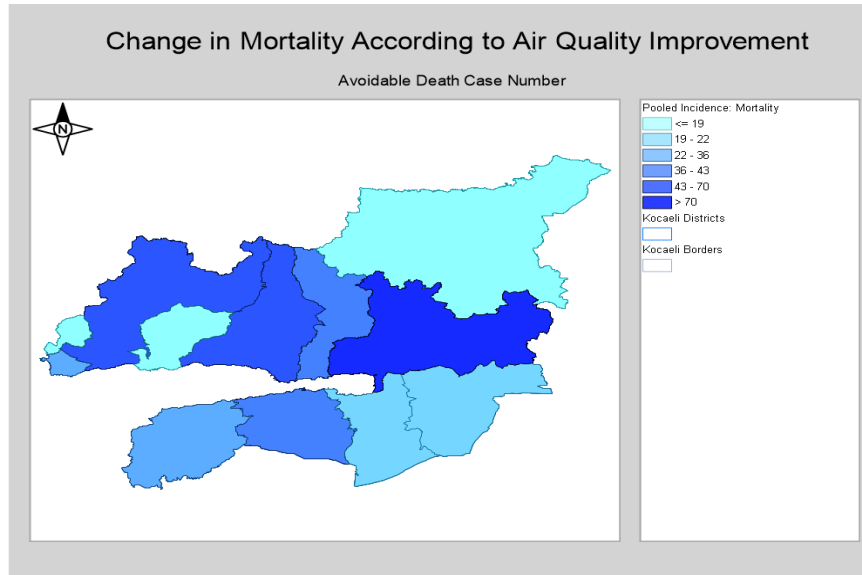


Figure 3.5 : Predicted Mortality according to %64 Reduction (OBS).

As in Figure 3.6, it can be seen that the smallest valuation of health costs belong to Dilovası in all districts. The predicted valuation of health costs are correlated with the number of mortality cases and indirectly correlated with population density. Therefore, Gebze and Izmit districts have the biggest valuation of all districts.

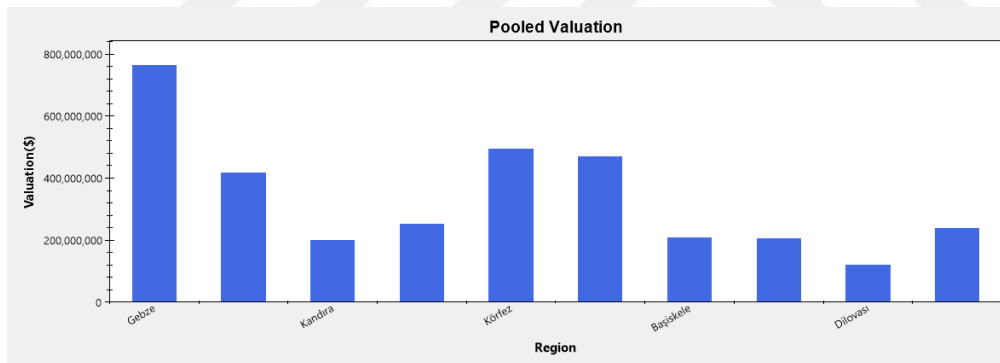


Figure 3.6 : Predicted Valuation of Health Costs (%64 Reduction with OBS).

In Table 3.2, the health and economic value of Izmit district has the biggest valuation and the number avoided mortality of all socio-economic results from two scenarios. In the BenMAP-CE's %64 run with measurement, Dilovası has 11 avoided death cases, which is the highest number in all BenMAP-CE scenario results for Dilovası.

Table 3.2 : BenMAP-CE's Results of %64 Run with OBS.

Kocaeli Districts	Number of Avoided Death Cases	Valuation of Prevented Health Expenses
Gebze	70	765 million \$
Gölcük	38	418 million \$
Kandıra	18	201 million \$
Karamürsel	23	253 million \$
Körfez	45	493 million \$
Derince	43	468 million \$
Başiskele	19	208 million \$
Çayirova	19	206 million \$
Darica	36	391 million \$
Dilovası	11	119 million \$
İzmit	125	1.3 billion \$
Kartepe	22	239 million \$

Compared to the air quality change in BenMAP-CE run with observational data, the amount of change in PM₁₀ concentrations in districts is lesser in Figure 3.7. On the other hand, Dilovası district is classified in the second group in terms of the amount of air quality change in both BenMAP-CE runs. Gebze and Karamürsel districts are placed in the second group with Dilovası, the lowest change in air quality is seen in Kandıra and İzmit districts in this run. Different from Figure 3.4, Darica and Çayirova have the biggest change in air quality in this run's result.

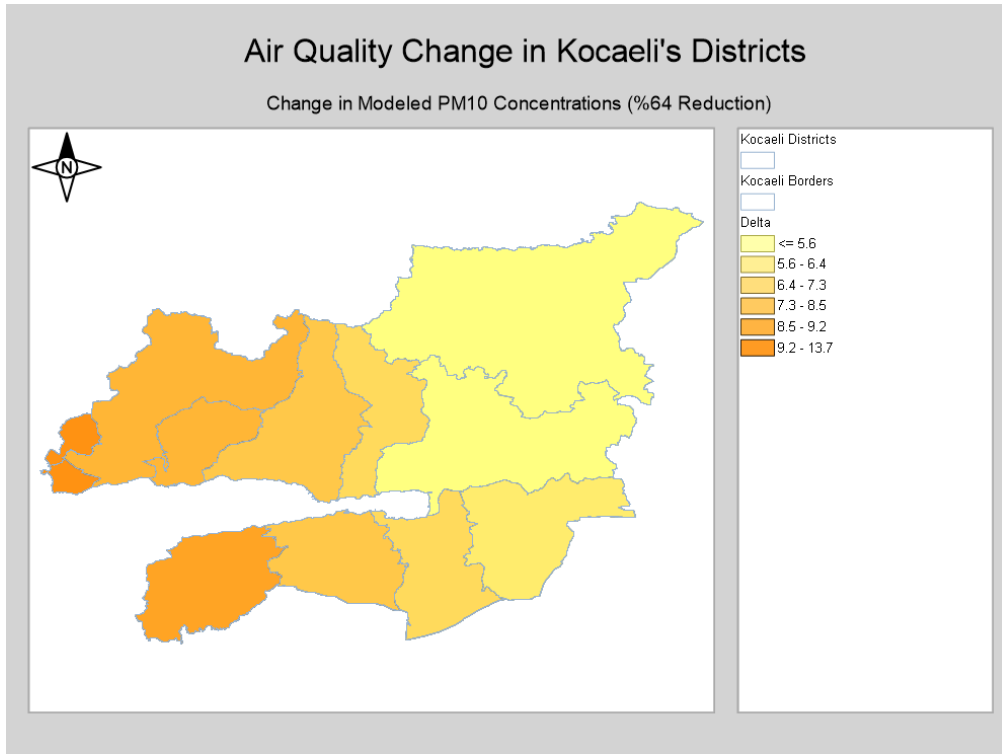


Figure 3.7 : Air Quality Change in Kocaeli (%64 Reduction with MOD).

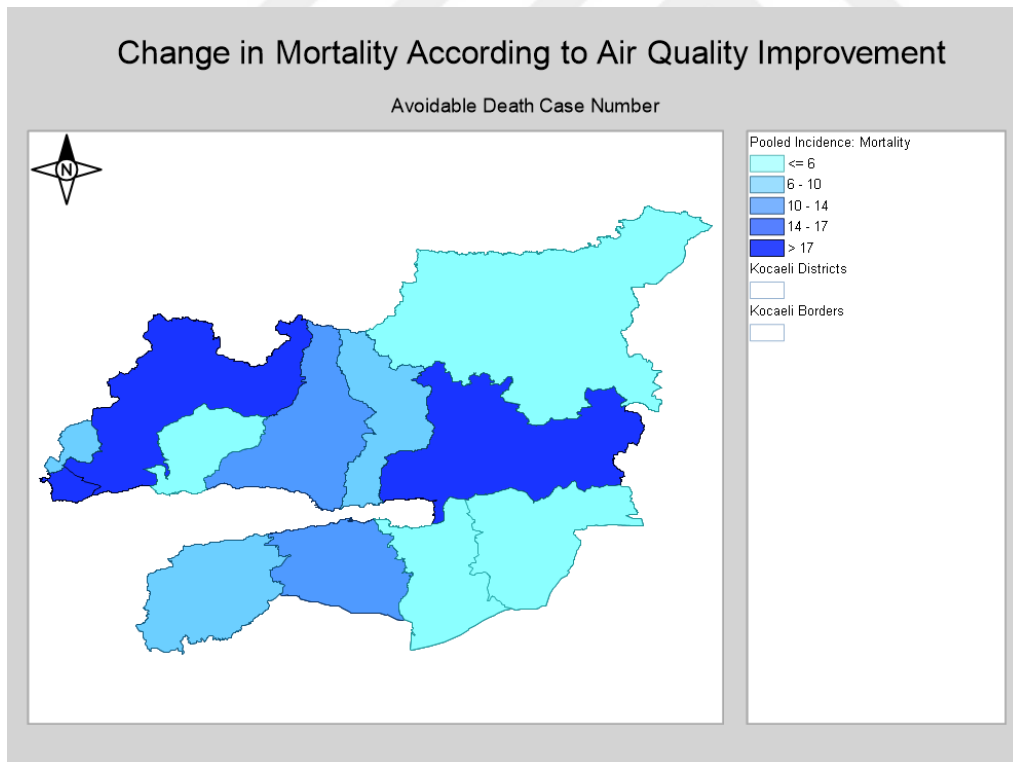


Figure 3.8 : Predicted Mortality according to %64 Reduction (MOD).

Figure 3.8, the highest numbers of avoidable death cases are seen in Izmit, Gebze and Darica districts. Since the air quality change in Izmit is less than Gebze and Darica districts but have the highest number just like Gebze and Darica districts, the mortality function is thought to give more importance to the exposed population than the amount of air quality change under these baseline PM₁₀ concentrations. Figure 3.9 shows the pooled economic valuation for some districts including Dilovası and Gebze in Kocaeli. In terms of the valuation of health expenses, Gebze is a superior district to other districts with almost 200 million \$. In contrast, Dilovası has the lowest number among the other districts with almost 30 million \$.

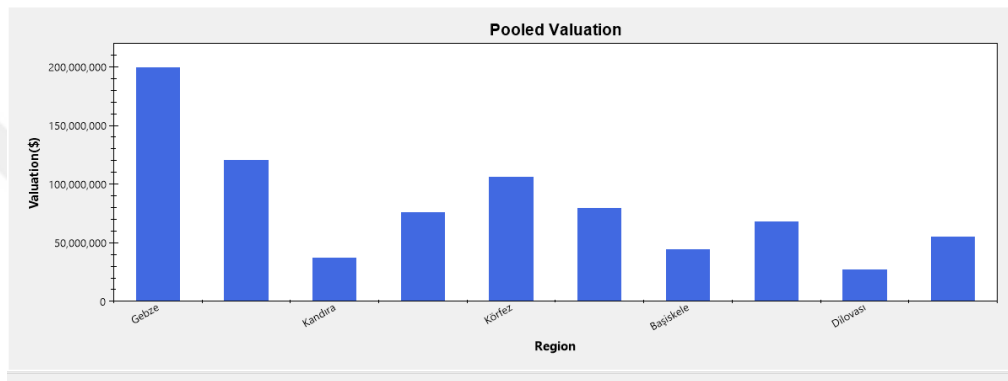


Figure 3.9 : Predicted Valuation of Health Costs (%64 Reduction with MOD).

On the comparison of both BenMAP-CE runs, the avoidable death case number of Dilovası decreases to three in this run as seen in Table 3.3. Nevertheless, the valuation of health expenses for Dilovası can't be underestimated in terms of saving money for a sustainable future for the district. The highest numbers are thought to be correlated with the population data of districts because one of the general purposes of HIF is the determination of exposure population. The reason for the decrease in this run's parameters is the underestimation of the modelled concentrations.

Table 3.3 : BenMAP-CE's Results of %64 Run with MOD.

Kocaeli Districts	Number of Avoided Death Cases	Valuation of Prevented Health Expenses
Gebze	21	199 million \$
Gölcük	13	120 million \$
Kandıra	4	37 million \$
Karamürsel	8	76 million \$
Körfez	11	106 million \$
Derince	8	79 million \$
Başiskele	5	44 million \$
Çayırova	7	68 million \$
Darica	18	168 million \$
Dilovası	3	27 million \$
İzmit	18	172 billion \$
Kartepe	6	55 million \$

3.2 Intelligent Transportation System Scenario with Wind Speed and Direction

In this chapter, the calculation of percentage improvement of air pollution needed for BenMAP-CE is explained and the yearly wind rose of Dilovası is given. Lastly, the health and economic outcomes from the BenMAP-CE program run with WRF-Chem model output data and air quality measurement data are examined and the interpretation of all scenarios' results are made.

3.2.1 Wind Speed and Direction Analysis of Dilovası for 2018

In this scenario, the proportion of winds except for prevailing directions, secondary wind direction and tertiary wind direction, with a wind speed higher than 0.2 m/s, was calculated according to the previously determined redirection conditions. This rate has a rate of 29% among all wind speed and direction values for 2018. This calculated ratio is given to the BenMAP-CE program as a percentage reduction. The percentage values in Table 3.4 are representing the frequency of every wind speed category in all datasets.

Table 3.4 : Frequency of every wind speed category (%).

0-0,2 m/sn	0.3-1.5 m/sn	1.6-3.3 m/sn	3.4 - 5.4 m/sn	5.5 - 7.9 m/sn	8.0 - 10.7 m/sn
~%0.01	~%16.1	~%48.6	~%25.6	~%8.1	~%0.13

Figure 3.10 shows the wind rose of Dilovası in 2018 and it is seen that the northeast direction is the dominant wind direction, and the secondary and tertiary directions are the north and east directions, respectively. The regions coloured in Figure 3.10 are the representation of the wind speeds as in the pie chart. The majority of wind speeds are placed between 1.6 - 3.3 m/s and 3.4 - 5.4 m/s for every wind direction and there are almost no winds classified as calm winds as can be seen from Table 3.4. The winds between 8.0 - 10.7 m/s are mostly placed in the north direction.

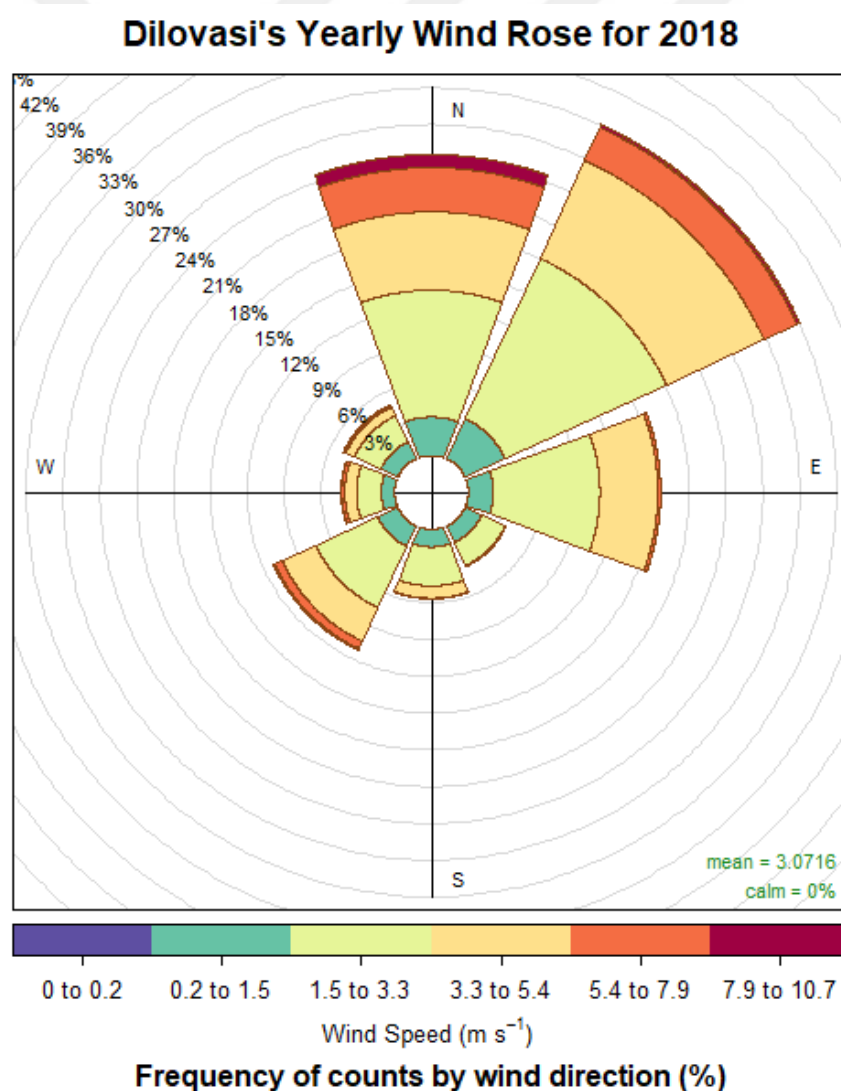


Figure 3.10 : The Wind Rose in Dilovası for 2018

3.2.2 Economic and Health Outputs for WSD ITS Scenario

Economic and health outputs from the BenMAP-CE with measurement dataset from the MoEU will be discussed in this section. The numbers of mortality and health expenses are the exact number predicted for possible air pollution reduction of %29. Figure 3.11 shows the air quality change under %29 air quality improvement. Like the previous maps for air quality change in Kocaeli's districts, Dilovası is classified in the second group in terms of the amount of change. The map is almost the same as Figure 3.4 with a different amount of change in all districts. The change in the air quality of Dilovası is between 14.20 - 16.19 $\mu\text{g}/\text{m}^3$ almost %50 amount of concentrations in BenMAP-CE's %64 run with measurement data.

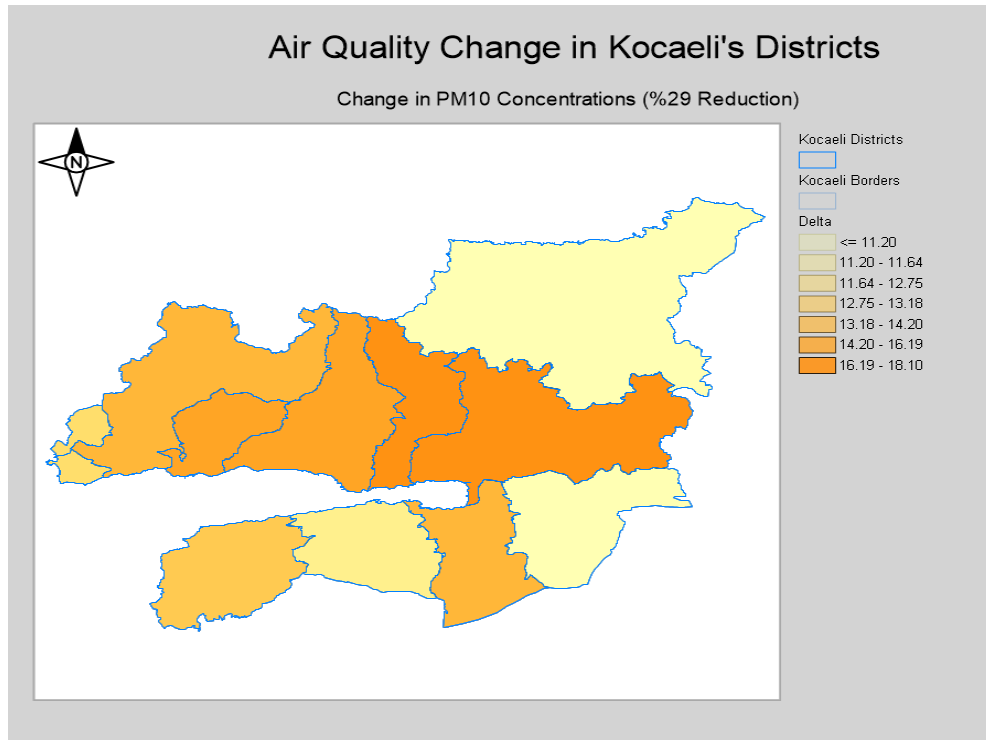


Figure 3.11 : Air Quality Change in Kocaeli (%29 Reduction with OBS).

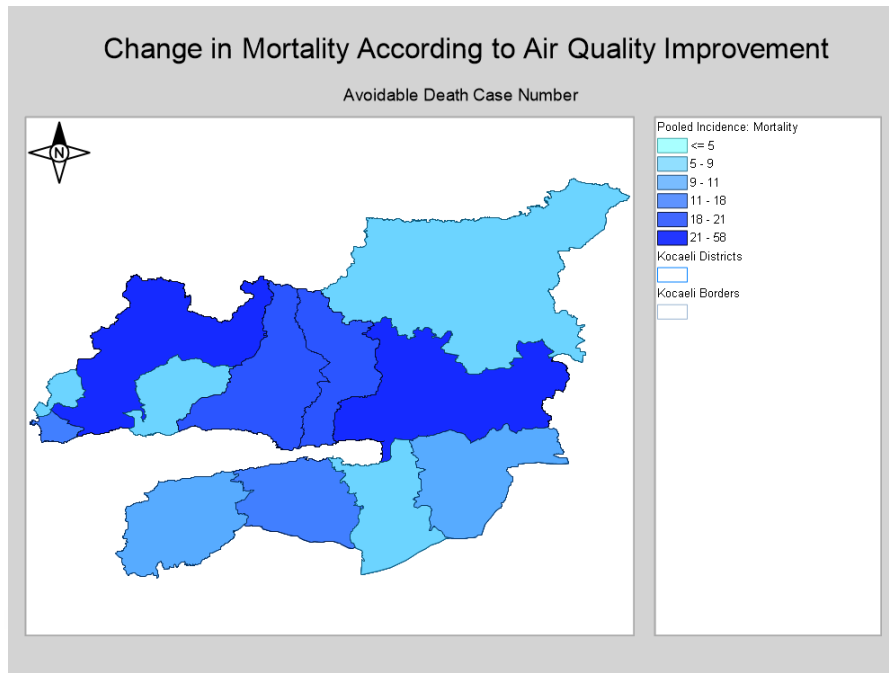


Figure 3.12 : Predicted Mortality according to %29 Reduction (OBS).

In Figure 3.12, the prediction of avoidable death case numbers under %29 improvement are shown. It is understood that Dilovası is one of the least districts in terms of change of mortality.

Also, there are districts coherent with the amount of air quality change such as Izmit and Gebze in BenMAP-CE runs with measurement but Dilovası isn't one of these districts due to having the least population among all districts. Figure 3.13 presents the predicted valuation of health expenses belonging to some districts in Kocaeli. In this figure, Gebze has the highest amount and Dilovası has the least amount of all districts.

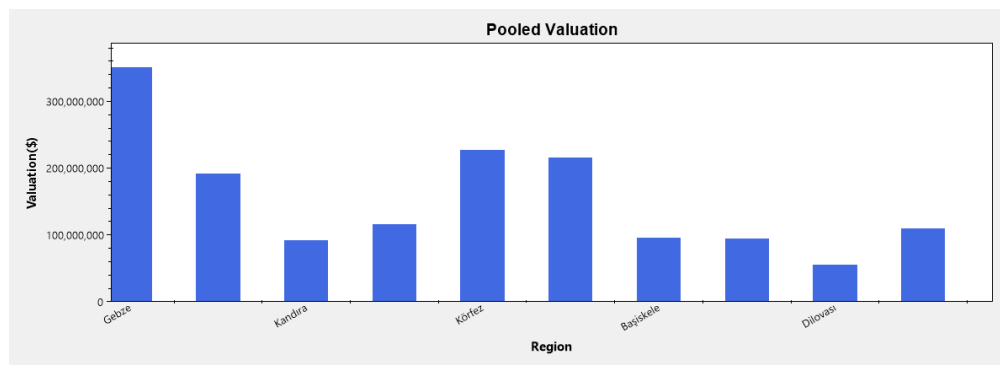


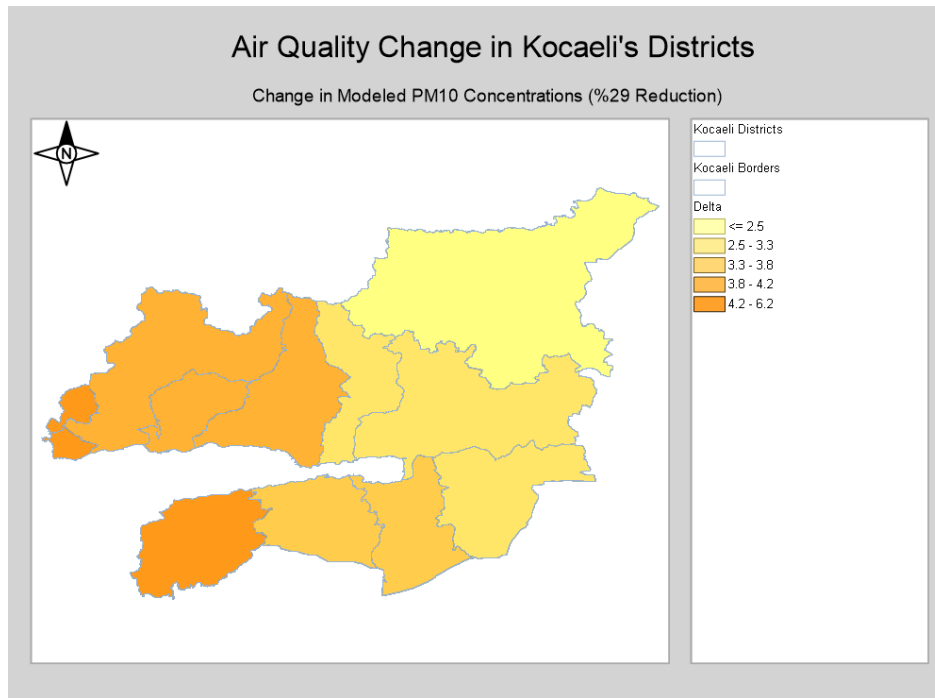
Figure 3.13 : Predicted Valuation of Health Costs (%29 Reduction with OBS).

The number of avoided death cases for the age group between 0 - 99 and the valuation of health expenses is presented in Table 3.5.

Table 3.5 : BenMAP-CE's Results of %29 Run with OBS.

Kocaeli Districts	Number of Avoided Death Cases	Valuation of Prevented Health Expenses
Gebze	32	351 million \$
Gölcük	18	191 million \$
Kandıra	8	92 million \$
Karamürsel	11	116 million \$
Körfez	21	227 million \$
Derince	20	215 million \$
Başiskele	9	95 million \$
Çayırova	9	94 million \$
Darica	16	179 million \$
Dilovası	5	54 million \$
İzmit	58	631 million \$
Kartepe	10	109 million \$

The highest number of avoided death cases belong to the İzmit district while the smallest number of avoided death cases belong to the Dilovası district. The reason behind this situation is thought that the HIF used in BenMAP-CE gives the priority to all districts' population data. Compared to %64 run results with OBS, the number of avoidable mortality and health expenses in this run decreased to 5 people and 54 million \$ for Dilovası for 2018.

**Figure 3.14 : Air Quality Change in Kocaeli (%29 Reduction with MOD).**

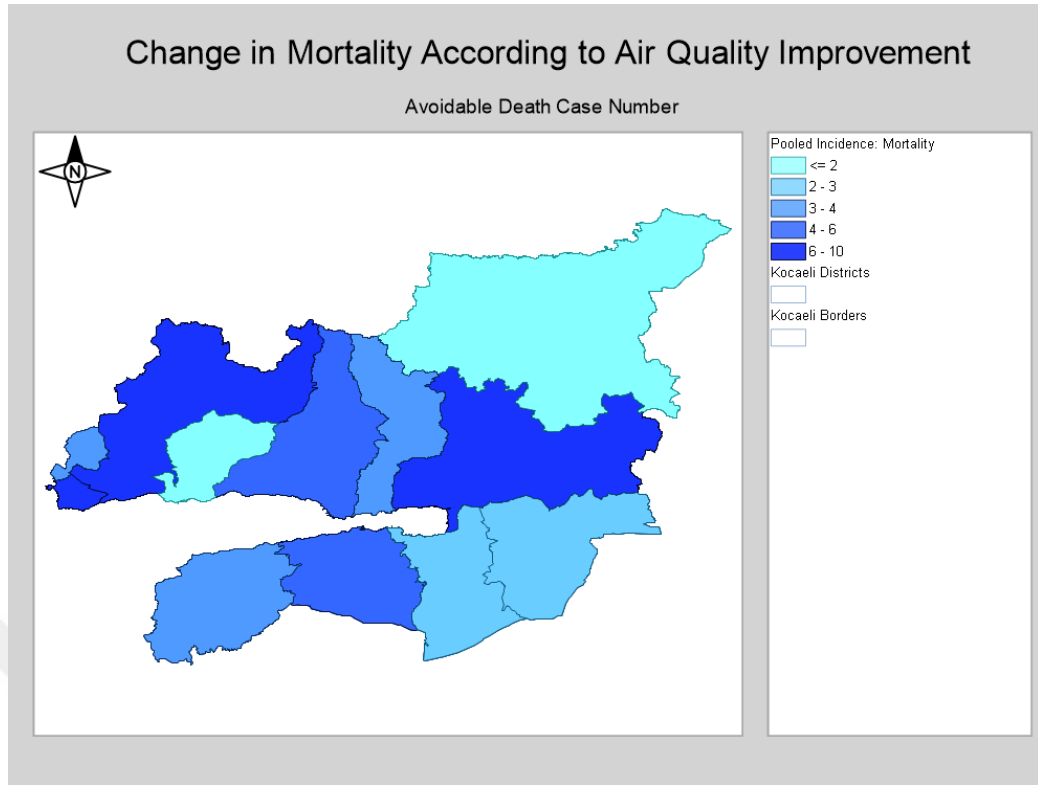


Figure 3.15 : Predicted Mortality according to %29 Reduction (MOD).

Figure 3.14 and Figure 3.15 shows the air quality change and mortality change under %29 improvement with WRF-Chem model output. The results are the lowest numbers compared to all scenarios' results. The maximum mortality number belongs to Gebze with ten people. The air quality change is between 0 - 6.2 $\mu\text{g}/\text{m}^3$ for all districts which is quite small compared to other results. The change of air quality in terms of PM_{10} concentrations for Dilovası is between 3.6 - 4.2 $\mu\text{g}/\text{m}^3$ which equals the smallest change of mortality.

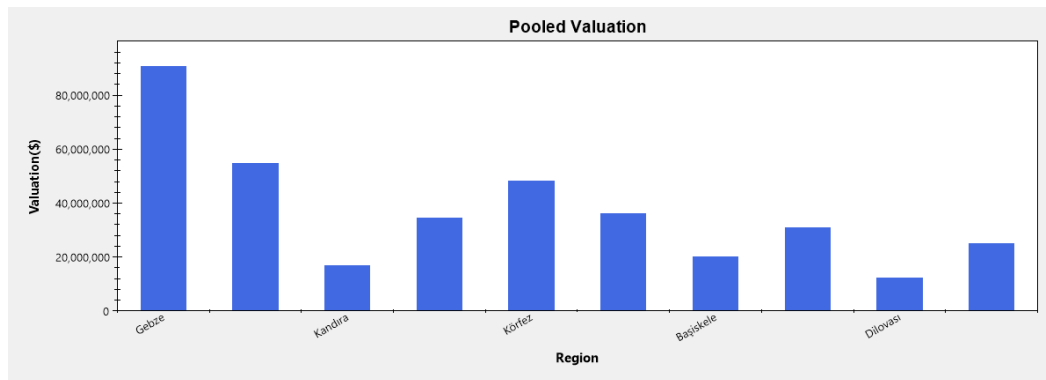


Figure 3.16 : Predicted Valuation of Health Costs (%29 Reduction with MOD).

Figure 3.16 presents the predicted valuation of health expenses for some districts in Kocaeli. The maximum valuation belongs to Gebze with 90 million \$ and the

minimum valuation belongs to Dilovası with 12 million \$. It can be understood from Table 3.6 that the reasons for the lowest numbers in this run is related to the underestimation of the model and the reduction percentage of the WSD scenario is lower than the AQI scenario.

Table 3.6 : BenMAP-CE's Results of %29 Run with MOD.

Kocaeli Districts	Number of Avoided Death Cases	Valuation of Prevented Health Expenses
Gebze	10	90 million \$
Gölcük	6	54 million \$
Kandıra	2	17 million \$
Karamürsel	4	34 million \$
Körfez	5	48 million \$
Derince	4	36 million \$
Başiskele	2	20 million \$
Çayırova	3	31 million \$
Darica	8	76 million \$
Dilovası	1	12 million \$
İzmit	8	78 million \$
Kartepe	3	25 million \$

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, the socio-economic and health impact of air pollution reduction by percentage in Dilovası district and city of Kocaeli is evaluated with the BenMAP-CE program with two optional air pollution datasets from air quality stations and WRF-Chem model gridded output.

One of the biggest advantages of the study is that it is the first study conducted with BenMAP-CE in Turkey, however, default options are generally used for all the processes in the program. It can be Although the importance of air pollution is known to people, in this study, a program such as BenMAP-CE has shown how effective the results of air pollution change are in terms of economy and health. Contrary to this, it is not sufficient to examine only the economy and health, and it is necessary to add to these areas. As a result, it is thought that public awareness can be increased against air pollution and climate change, which are specially sourced by anthropogenic emissions.

The performance analysis for the WRF-Chem model shows that the biggest correlation between model data and measurement data is seen in Dilovası but in terms of all error metrics, the most successful station is Gebze station. Lastly, mean bias values present that the model underestimates in general. The results can be improved by changing physical and chemical options or using linear fitting for the modelled results. Improvement for the WRF-Chem results is thought to improve the BenMAP-CE results, too.

The results from AQI and WSD scenarios shows that the scenario created according to AQI values have higher socio-economic results for Dilovası due to a higher reduction percentage for air pollution. Also, the air quality change of BenMAP-CE runs with measurement is better than the runs with modelled data due to underestimation of the model compared to observation data. Since HIF is correlated with exposed population data, districts like Gebze and Izmit have a higher number of avoidable death cases caused by air pollution compared to Dilovası's results.

Nevertheless, it is important to remember that even the lowest valuation for Dilovası can not be underestimated.

The detailed socio-economic and health analysis impact of air pollution contains the long-term research and development, literature review processes. It is thought that more information on the methodology of epidemiology studies are needed for further health impact assessment studies which means the need for a collaboration of another expert of epidemiology and economy.

In future studies, a similar socioeconomic analysis can be made with this program for other regions and cities having low air quality in Turkey. It is also considered that socio-economic analysis of possible emission reduction scenarios with the output of state-of-art models like earth-system model, climate models in the future.

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