ASSESING PARTICLE POLLUTION IN THE ØSTERBRO DISTRICT OF COPENHAGEN

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This report represents work of WPI undergraduate students submitted to the faculty as evidence of a degree requirement.

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ABSTRACT

Miljøpunkt Østerbro, located in the Østerbro district of Copenhagen, Denmark, aims to raise awareness of health effects caused by air pollution through a visual display of air pollutant concentration. Our team will measure air pollutant concentrations throughout the Østerbro district, and visualize the data for distribution to Østerbro residents. We will submit our results to Miljøpunkt Østerbro to aid in the realization of their goal.

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CHAPTER 1. INTRODUCTION

Air pollution causes 2.4 million deaths per year, globally (Guilford, 2013). Of anthropogenic pollutants, those created by humans, 13% are from mobile sources (Intergovernmental Panel on Climate Change, 2007). Health issues that arise from air pollution are often seen in and around urban areas as a result of the high concentrations of vehicular emissions. The main health issues resulting from high pollution concentrations occur in the respiratory system, most noticeably affecting the elderly or young children (Davies, Vlaanderen, Henderson, & Brauer, 2009).

Currently, many Danish citizens believe that air pollution is the most important environmental issue and this concern is reflected in the Danish government ("Clean Air," 2012). In an attempt to be more environmentally friendly, the Danish government created several long term plans to reduce pollution and their negative effect on the environment and health of citizens ("Clean Air," 2012). Although the majority of Danish roadways have low pollution concentrations, some are above standards set by the World Health Organization (WHO) followed by the European Union (European Environmental Agency, 2010). Unfortunately these plans do not immediately reduce the negative health effects of air pollution on commuters. As of 2010, an estimated 3400 Danes prematurely die per year because of current city air quality (European Environmental Agency, 2010). Østerbro, a residential district of Copenhagen, is of particular concern with regards to the negative health effect solution because of its large population of at-risk members such as elderly and young children (Lene Midtgaard, personal communication, 2014).

While there is pollution data for Copenhagen as a whole, there is little information on the pollutants in the Østerbro area (Nielsen & Jensen, 2010). Our sponsor, Miljøpunkt Østerbro, is a non-governmental organization that focuses on sustainability. Previous projects focus on the impact of pollutants on children and provide ways to avoid or reduce exposure to pollutants. The main objective of this project is to create a heat map to visualize pollutant concentrations in the Østerbro district. To achieve our objective, our team will measure pollutants near bike paths, roads, and parks in Østerbro to determine which areas are the least polluted. With this information, Østerbro residents can avoid areas of high pollutant concentration and improve their health.

CHAPTER 2. LITERATURE REVIEW

This chapter provides a comprehensive exploration of Denmark's progressive attitude, the causes of different types of pollution, and influences on pollution distribution. The chapter also provides a detailed explanation of the short and long term negative health effects of air pollution, particularly those caused by exposure to particulate matter. Finally, the chapter examines the options for visualization of spatial data, distribution of information, and psychology of habit change. All of the topics covered are important to consider when providing visual information for Østerbro residents.

2.1 Denmark

Historically, Denmark has taken a progressive stance on environmental issues. During the 1960s, traffic overran many of Denmark's cities ("How Denmark became a cycling nation," 2014). In response to increasing traffic and the emissions they produce, the Danish Government created the Ministry of the Environment. After the Ministry's establishment in 1971, many conflicts arose surrounding car and bicycle interests in the cities, resulting in increased bicycle lanes and space for pedestrians (Ministry of the Environment, 2014). In recent years, the public's focus is climate change and the health effects associated with pollution ("How Denmark became a cycling nation," 2014).

Denmark's focus on climate change and health effects spurred a series of initiatives and plans at both the national and municipal level. The most well-known plan, and first of its kind, is the Energy Strategy 2050, also known as the 2050 Plan. The 2050 Plan aims to make Denmark fossil fuel independent by 2050 (The Danish Government, 2011). To keep the plan on track, at least 35% of Denmark's total energy need must be comprised of renewable sources by the year 2020 (Lidegaard, 2012). If successful, the 2050 Plan will create a fossil fuel free country, reduce pollution concentrations, and set an example for other countries.

At a municipal level, Copenhagen has several strategies to increase bicycle use and improve the health of its residents. In 2008, Copenhagen politicians unanimously decided to make Copenhagen an eco-metropolis (The City of Denmark Traffic Department, 2014). This initiative focuses on making Copenhagen the "world's best city for cyclists" and includes goals to create a cleaner, healthier and more environmentally friendly city ("Copenhagen's Bicycle Strategy & Policies," 2014). In order to reach this goal, Copenhagen has made plans to improve upon both national and international standards of harmful air pollutant concentrations by the year 2015 (City of Copenhagen, 2008). The eco-metropolis vision aims to increase the number of cyclists and pedestrians in order to reduce the number of cars and amount of air pollution.

2.1.1 Pollution in Copenhagen

The 2050 Plan states that "the air should be so clean that Copenhageners health will not be damaged [by 2015]" ("Clean Air," 2012). Residents of Copenhagen believe air pollution is the most important environmental issue that their city faces in regards to public health. A road in downtown Copenhagen, H.C. Andersens Boulevard, is a quintessential example of the goals set by the 2050 Plan. H.C Andersens Boulevard has decreased the concentration of particulate matter less than 10 micrometers in size (PM_{10}) by 50% between 2002 and 2010, as well as consistently staying under the new European Union (EU) limit of 25 μg/m^3 for particulate matter less than 2.5 micrometers in size ($PM_{2.5}$) since 2007 ("Clean Air," 2012). The yearly average pollution concentrations of H.C. Andersens Boulevard are shown in Figures 2.a and 2.b. Though the average levels are below health standards, high amounts of traffic in the city can still produce spikes in concentration that may be harmful to Østerbro residents.

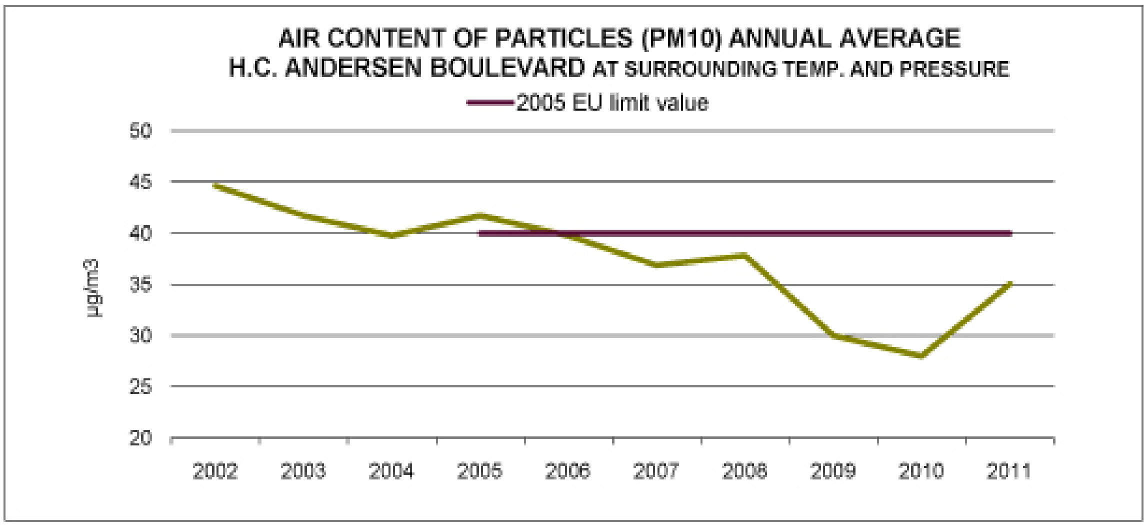

Figure 2.a: ("Clean Air," 2012)

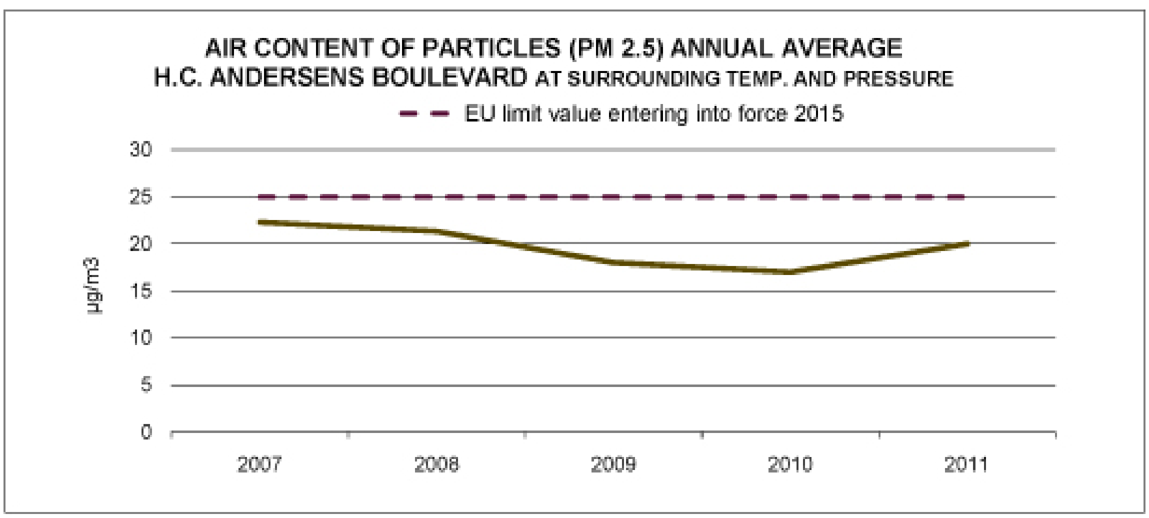

Figure 2.b: ("Clean Air," 2012)

2.1.2 Østerbro

Copenhagen is comprised of ten districts. Østerbro is a residential district located northeast of downtown Copenhagen, close to the city while still providing a green environment (Relocation, 2014). The Østerbro district, in relation to the rest of Copenhagen, can be seen in Figure 2.c. The area in Østerbro is quiet, with plentiful houses, playgrounds, parks, day cares, and kindergartens (Lene Midtgaard, personal communication, 2014). The majority of the businesses in Østerbro are on Østerbrogade, one of the two main shopping streets (Relocation, 2014). Østerbrogade starts at the Trianglen and extends north to Søerne. Currently, there is a lack of air pollution data in the district, which could increase direct exposure and associated adverse health effects on the residents (Nielsen & Jensen, 2010).

Figure 2.c: A map of Copenhagen, the district of Østerbro is green. (Copenhagen Districts, 2008)

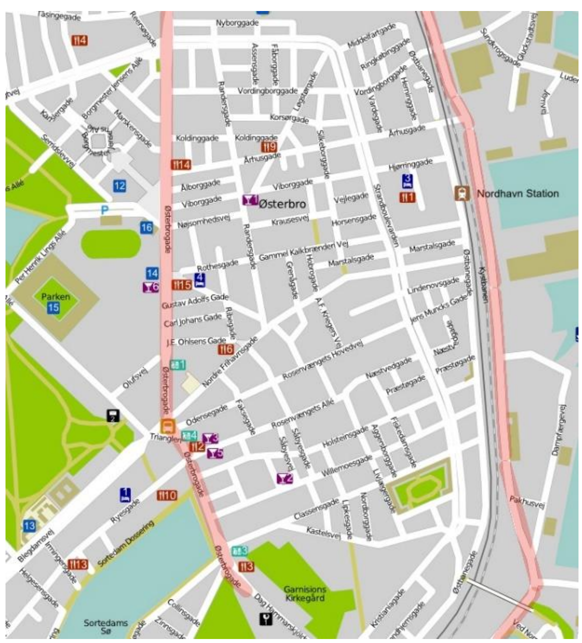

Figure 2.d: Close up of Østerbro. The Main Roads are highlighted in red (Østerbro Map, 2009)

2.2 POLLUTION SOURCES

Human activity does not create the majority of airborne pollution; in fact, only about 10 percent of all aerosols are anthropogenic (Voiland, 2010). Despite being only one-tenth of global atmospheric aerosols, anthropogenic aerosols are found in higher concentrations than natural aerosols in urban and industrial areas (Voiland, 2010). These pollutants can be produced by either stationary or mobile sources and have varying health effects depending on their location. Stationary sources--industry, agriculture, forestry, waste and wastewater, commercial and residential buildings, and energy supply-- comprise 87 percent of anthropogenic greenhouse gas production globally, as seen in Figure 2.e. The mobile sources, or transportation, comprise the remaining 13 percent.

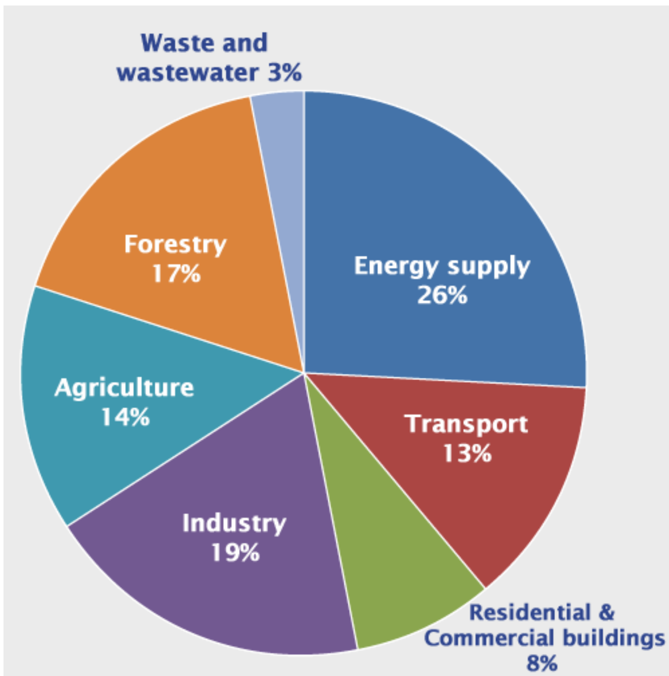

Figure 2.e: Greenhouse gas emissions by economic sector in the United States in 2011 (Intergovernmental Panel on Climate Change, 2007).

Particulate pollutants, the main focus of this project, can be broken down into three categories: coarse, fine and ultrafine. Coarse particles are defined as PM_{10}; fine particles are defined as $PM_{2.5}$; ultrafine particles are defined as $PM_{0.1}$, with a diameter of less than 0.1 micrometers (Brunekreef, 2002). All of these particulate pollutants cause adverse effects on the human body. The health effects caused by particulate pollutants are explored in section 2.3.

2.2.1 Stationary Sources

Stationary pollution is composed of many natural sources of air pollution, along with human sources. The most visible natural causes of pollution are volcanic eruptions and dust storms. Other natural causes of pollution can be as simple as respiration in animals, or as complex as creation of radon gas from the decay of radium in the Earth's crust. The majority of anthropogenic stationary-source pollutants are from power plants and industry (Environmental Protection Agency, 2013). These anthropogenic sources have varying effects on the global ecosystem (Environmental Protection Agency, 2013).

Any source of pollution increases the concentration of pollutants in the immediate area; therefore, city planners purposely position many anthropogenic stationary pollution sources outside of city limits to have the least impact on residents. Though stationary sources are often positioned outside a city, their effect establishes a baseline pollution level within the area. While this level may change due to weather and other natural events, it is relatively consistent ("Factors Affecting Air Quality," 2014). This baseline accounts for a large percentage of total anthropogenic aerosol pollutants, with mobile sources accounting for the rest. Since the baseline is relatively consistent from day to day, the stationary pollution sources will have a fairly constant effect on the health of local residents. The baseline pollution concentration is largely unavoidable and will therefore not be the focus of this project.

2.2.2 Mobile Sources

Mobile sources can be located within the city, in close proximity to pedestrians, and therefore have the potential to directly expose residents to hazardous pollutants. The most avoidable sources of anthropogenic pollutants are created by cars and other means of transportation. On-road vehicles directly produce carbon monoxide, carbon dioxide, nitrogen monoxide, hydrocarbons, sulfur dioxide and particulates; whereas, ozone, nitrogen dioxide, and acid vapors are created secondarily, through chemical reactions of the primary vehicle emissions with outside elements (Brunekreef & Holgate, 2002). Since, individually, these sources are small, it is possible to avoid high pollutant concentrations by avoiding high concentrations of vehicle traffic. Avoiding high pollutant concentrations as a pedestrian or cyclist can be as simple as traveling at a different time or taking a less congested route.

2.2.3 Meteorology Effects on Pollution

Weather has many effects on air pollution, which are important to consider when attempting to properly measure air pollution concentrations. The main factors affecting air quality are wind, temperature, and humidity (Environmental Protection Authority, 2013). Each of these factors has its own set of hindrances, which can compound when considering multiple variables at once.

Wind, when combined with a valley-like structure, much like the buildings surrounding a city street, can create a recirculation effect as seen in Figure 2.f (Wang, van den Bosch, & Kuffer, 2008). When a crosswind is blowing, the buildings cause air to be trap and recirculated, which prevents dispersal of the pollutants. This creates an imbalance of pollution concentration on the street level, where walking on the leeward side of the street will expose a pedestrian to much higher concentrations of pollution than the windward side. On especially windy days, pedestrians often opt to take the leeward side of the road, which exposes residents to much higher pollutant concentrations (Wang, van den Bosch, & Kuffer, 2008).

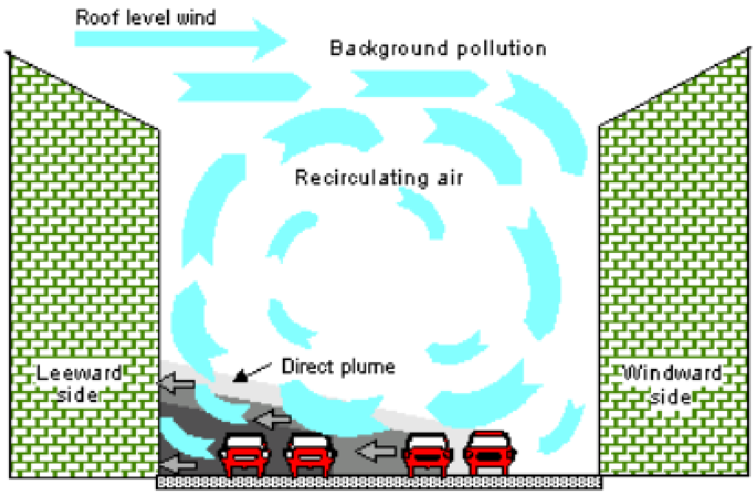

Figure 2.f: Wind flow in a street canyon (Berkowicz, 2000)

When combining the recirculation effect with temperature inversion, it becomes possible for pollutants to be trapped on the street level for extended periods of time. Temperature inversion primarily occurs in valleys, when a pocket of cold air is trapped below warmer, ambient air ("Factors Affecting Air Quality," 2014). The cool air below is denser and will not mix well with the warmer, less dense air above. The lack of mixing will trap any pollutants at the street level. Temperature inversion is most often seen during the night into morning ("Factors Affecting Air Quality," 2014). When combined with the recirculation effect, temperature inversion can, in some cases, cause pollution from the afternoon rush hour to be trapped at street level until the next day's morning rush hour. This causes many commuters and residents to be exposed to unnecessarily high levels of pollution.

Rain suppresses dust and other pollutants in the air (Agency, 2013). The rain absorbs these pollutants and deposits them on the ground when the rain lands, decreasing the concentration of pollutants in the air. Rain also impacts the ability of many pollutant measurement devices to function, potentially damaging them; measurement on days with precipitation is inadvisable due to this fact. Since rain reduces the amount of airborne pollution exposure to residents, the inability to measure on rainy days should have minimal impact on our data.

2.3 Health Effects

During the 1970’s to 1990’s, there was a transition from petrol-driven to diesel-driven vehicles throughout Europe (Dockery & Pope, 1994). This switch has negatively affected global climate change, in addition to increasing air pollution concentrations to alarming levels in most European locations (Dockery & Pope, 1994). The vehicular emissions and their subsequent secondary products described in section 2.2.2 are becoming more prevalent and affecting people in subtle and life-threatening ways.

Those at higher risk to develop complications from direct exposure to particulate matter are children, elderly, and those with preexisting conditions (Commission, 2007). Particulate matter affects children developmentally, particularly concerning lung function, while elderly suffer intense immediate effects such as dizziness, wheezing, and irritation of airways (Davies, Vlaanderen, Henderson, & Brauer, 2009).

2.3.1 Air Quality Baseline

The World Health Organization (WHO) has set up an Air Quality Index for Europe regarding a variety of different particulates and chemical compounds (“Air quality guidelines,” 2005). The Air Quality Index is a set of tested and established guidelines based on the amounts and the duration of time a person can be exposed to a certain compound, while still being considered healthy. When a person exceeds these guidelines, that person may begin to experience short-term side effects as well as developing long-term conditions. The concentration of an air pollutant is given in micrograms (one-millionth of a gram) per cubic meter air or $\mu g/m^3$.

Particulate size	Annual mean	24-hour mean
<10 µm	20 $\mu g/m^3$	50 $\mu g/m^3$
<2.5 µm	10 $\mu g/m^3$	25 $\mu g/m^3$
<0.1 µm	unestablished	unestablished

Table 1: WHO guidelines concerning different sizes of particulate matter (“Air quality guidelines,” 2005)

2.3.2 Cardiovascular and Respiratory Effects

The most common immediate respiratory effects from inhalation of vehicular emissions are wheezing, dizziness, and irritation of airways. Long-term cardiovascular and respiratory effects largely depend on the size of particulate matter. Three general biological pathways shown in Figure 2.g, account for the majority of cardiovascular complications associated with inhalation of particulate matter.

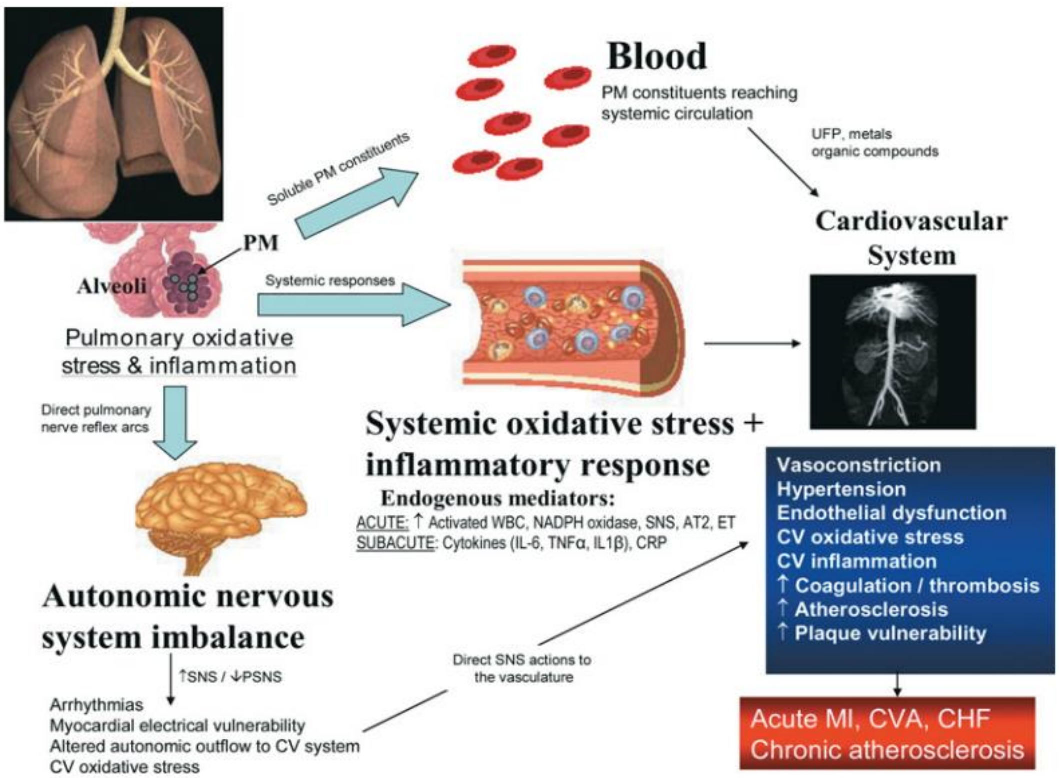

Figure 2.g: PM causing CV events via biological pathways (Brook, 2008). AT2, (angiotensin II); CVA, (cerebrovascular accident); CHF, (congestive heart failure); ET, (endo-thelins); MI, (myocardial infarction); ROS, (reactive oxygen species); UFP, (ultra-fine particles); WBC, (white blood cells)

$PM_{0.1}$ are small enough to enter the bloodstream when inhaled and circulate throughout the body systemically shown in the top pathway (denoted by the topmost shaded arrow) of Figure 2.g. Systemic circulation gives $PM_{0.1}$ direct contact with the body's vital support systems and can alter their functions even on a subcellular level; electron microscopy has determined subcellular penetration and mitochondrial damage (Li et al., 2003).

The middle pathway of Figure 2.g shows systemic responses of particulate matter that is not small enough to enter the bloodstream. Coarse, fine, and ultrafine particulate matter have displayed systemic oxidative stress and inflammatory response in the body (Brook, 2008; Douglas, Haldane, & Haldane, 1912; Mills et al., 2008). Researchers link oxidative stress to more alarming diseases including cancer, Parkinson's disease, and Alzheimer's disease (Brook, 2008; Douglas, Haldane, & Haldane, 1912; Mills et al., 2008). When the body exhibits an inflammatory response, white blood cell count increases to fight against the infection or irritation. High white blood cell count can result in hypercoagulability causing shorter prothrombin time (Barron et al., 2001). Prothrombin time, or PT, is the amount of time measured for blood to clot. Higher concentrations of PM_{10} have been associated with shorter PT (Baccarelli et al., 2007; Douglas et al., 1912). Shorter PT from hypercoagulability may lead to increased risk for blood clots to form in blood vessels called thrombosis (Bick & Ucar, 1992). Depending on the size and location of these blood clots, thrombosis can result in a wide range of complications including stroke, pulmonary embolism (blockage of lung artery), and may even require surgery to remove the clot (Decousus et al., 1998). As PM_{10} concentrations increase by 1 μg/m3, hospital admissions for cardiovascular disease increase by 0.5% (Brunekreef & Holgate, 2002). (Brunekreef & Holgate, 2002).

Particulate matter in the air inhaled from vehicular emissions can damage small tissues and nerves of the lungs, affecting the autonomic nervous system, as indicated from the bottom pathway of Figure 2.g. The autonomic nervous system controls the body in many ways including the sympathetic nervous system (SNS) and parasympathetic nervous system (PSNS). PSNS activates when the body is at rest by keeping heart rate and blood pressure low. When SNS activates, the body prepares to fight by increasing heart rate and blood pressure ("Nervous and Endocrine Systems," 2008). If SNS triggers unnecessarily, it creates an imbalance of the PSNS and SNS states. The damage from particulate matter is shown to trigger SNS and cause cardiovascular conditions such as arrhythmia, vasoconstriction, and hypertension (Brook, 2008).

Pekkanen, Timonen, Ruuskanen, Reponen, & Mirme have found $PM_{2.5}$ to have the strongest correlation between exposure and cardiovascular complications than any other particulate matter size (1997; Pope et al., 2004). Short-term exposure at urban levels to $PM_{2.5}$ causes acute artery vasoconstriction (R. D. Brook et al., 2002). This directly results in acute cardiac events and demonstrates the severity of complications that can arise from exposure to these particulates, even when for a short duration of time (R. D. Brook et al., 2002).

2.3.3 Children

Children are high priority and high risk individuals concerning air pollution. A study conducted in Southern California analyzed the association between long-term exposure to ambient air pollution and the growth in lung function over an eight-year period. The study found a strong correlation between $PM_{2.5}$ inhalation and a clinically low forced expiratory volume in the first second (FEV1) as well as an increased risk of respiratory conditions that can cause complications and death later in adulthood (Gauderman et al., 2004). All three types of particulate matter is associated with decline in morning pulmonary expiratory flow (PEF). Short term increases in ambient air pollution increase mortality and morbidity in adults, children, and fetuses. Another study assessed in utero exposure to air pollutants and found that early childhood exposure plays a role in development of asthma (Clark, Demers, & Brauer, 2010). The environment in which a child develops influences their growth. Limiting a child's exposure to these particulates benefits their growth by promoting a healthier and longer life.

2.4 Distribution of Information and Habit Change

If citizens are unaware of where high concentrations of pollutants are found, they may be inadvertently exposing themselves to pollutants and the associated negative health effects. Our project intends to collect that data on pollution in order to increase awareness. We will need to spread the information as efficiently as possible either through web based information or physical media. We will also need to understand what encourages people to change their habits and if our information will be accepted or ignored. The application of these two areas of psychology will allow our project to provide techniques for Østerbro residents to change their travel habits.

2.4.1 Web Based Information versus Physical Media

There are two distinct realms of information distribution and display, either web-based or physical media. The inherent advantage of web-based information is its availability, whereas, non-web-based information has tangibility. A study of studies done by the University of California, San Francisco on 17 studies, 11,754 participants, examined the effect of web-based and non-web-based information on the habits of each subject (Wantland, Portillo, Holzemer, Slaughter, & McGhee, 2004). The university study produced a range of results but only the data supporting web-based is considered statistically significant (Wantland, Portillo, Holzemer, Slaughter, & McGhee, 2004). Of the studied outcomes, 16 of 17 studies revealed improved knowledge and/or improved habitual behavior in the subject that the individuals were studying, such as healthy exercise habits or more nutritious eating habits, when learning from web-based material (Wantland, Portillo, Holzemer, Slaughter, & McGhee, 2004). The success of web-based information supports individuals in maintaining a change in habit due to the flexibility, interactivity, and responsiveness of web programs.

2.4.2 Psychology of Habit Change for Health Benefits

An important aspect of our project is the willingness of residents of Østerbro to change their travel habits for health benefits. In Southern California, Matthew Neidell at Columbia University conducted a study on whether or not people respond to smog alerts. The study examined impacts at three outdoor activity centers during smog alerts, finding a negative correlation between smog alerts and attendance. An active smog alert decreased the attendance measured at every location (Neidell, 2005). As the frequency of smog alerts increased, and the more it affected people's everyday routines, the response to the alerts decreased (Neidell, 2005). The smog alerts must be accurate, because if they are innacurate, the alerts will no longer be trusted by the public and will be ignored (Bäck, 2013). Though our project is not about posting alerts, the information it provides must be accurate, or it will be ignored.

Another study on seatbelt use, a minor change with major potential health benefits, found that health benefits are less likely to convince adolescents to change their habits than adults (Schwarzer, 2008). Many people are willing to make a change for health benefits and use seatbelts, as the change does not heavily impact their normal routine (Schwarzer, 2008). Our project will prompt each individual to consider changing their travel routine based upon the perceived health benefits of avoiding air pollution.

2.5 Summary

Danes consider air pollution to be the most important environmental issue, but the plans implemented by the Danish government will not immediately resolve air pollution or reduce the adverse health effects. Air pollution data is available at the national and municipal level, but there is no data available at the district level. Miljøpunkt Østerbro recognizes that lack of data is an issue and wants to inform Østerbro residents about pollutant concentrations in the district. Street-level information will allow Østerbro residents to avoid areas of high pollutant concentration and the negative health effects associated with direct exposure to pollutants. Our project will help Miljøpunkt Østerbro by visualizing pollutant concentration data in order to improve the quality of life of Østerbro residents.

CHAPTER 3. METHODOLOGY

This project is designed to benefit the residents of the Østerbro district and improve their quality of life by visualizing pollution levels throughout the district**.** We will use the pollution data to determine safer travel routes and safer times for outdoor activity. We will accomplish this objective by measuring pollutants throughout the district and plotting the data. We will then convey the information to the residents of Østerbro through the use of the Miljøpunkt Østerbro website.

3.1 Assess Areas of Data Collection

Our main focus is visualization of anthropogenic pollutants caused by emissions from vehicles. Pedestrian and cyclist commuters will have the highest risk of pollutant exposure during rush hour traffic times. Copenhagen rush hour traffic occurs at approximately 7:30-9:15am and 3:00-5:00pm, Monday through Friday (Lene Midtgaard, personal communication, 2014).

A contributing factor to concentrations of pollutants in Østerbro is the closest power plant, H. C. Ørsted Power Station. This power plant is located at Enghave Brygge, Sydhavnen, and is approximately 6km, or 3.7 miles, south of the heart of Østerbro; however, this station will not produce spikes in pollution concentration, and will only affect the baseline levels. Thus, we will primarily take measurements on roadways that directly expose commuters to vehicular sources of pollutants.

Residents of Østerbro and our sponsor are primarily concerned about children's health caused by exposure to pollution. As discussed in section 2.3, children are high risk individuals and more susceptible to develop long-term complications. In Denmark, most nurseries, daycares, and kindergartens put children outside for their frequent daytime naps (Mygind, Rønne, Søe, Wachmann, & Ricks, 2003). Østerbro citizens are concerned about the quality of air outdoors that may pose risks to the children during these outdoor naps. In order to give accurate assessment of risks, we will need to determine the usual times these naps are taken. For instance, naps taken during or immediately after rush hour traffic may be at higher risk for exposure than naps taken in the middle of the day.

Our sponsor, Miljøpunkt Østerbro, will be providing a map of Østerbro indicating what specific roads and locations should be our focus. We will also be given the locations of playgrounds, day cares, and nurseries that are at high risk for exposure such as those closest to major roadways.

3.1.1 Major Roadways

Two of the major roadways in Østerbro are Kalkbraenderihavnsgade and Østerbrogade, shown in Figure 3.a. Kalkbraenderihavnsgade is a larger roadway than Østerbrogade and runs adjacent to the east edge of Østerbro. Østerbrogade will be the main focus for rush hour traffic pollution measurements and health effects on commuters due to its proximity to the majority of residential Østerbro. If our measurements conclude that commuting on these roadways during rush hour traffic times is hazardous to human health, alternative paths will be determined.

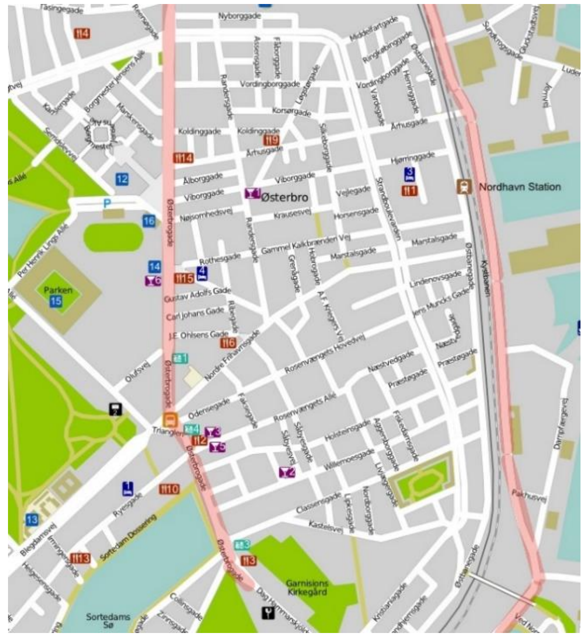

Figure 3.a: Close up of Østerbro. The Main Roads are highlighted in red (Østerbro Map, 2009)

3.1.2 Small Roadways

Designing safer alternate routes for pedestrian and cyclist commuters requires data measurements on smaller roadways. We will use the pollutant concentration measurements to identify safe roads as alternatives to commuting using larger roadways if necessary. Section 3.3 discusses visualization of pollutant concentrations that will be used to identify safe alternative roadways for commuters.

3.2 Measurement of Pollution

Measurement of pollution concentrations is an essential component to reach our main objective. The most important measurements must be taken during rush hour times, giving the project a narrower time window than the seven week schedule suggests. Miløjpunkt Østerbro has close ties with another non-governmental organization in the city, the Danish ECO Council. The Danish ECO Council will provide us with devices for pollution measurement. One of the devices provided may be a P-Trak Ultrafine Particle Counter (UPC) which measures the amount of small particles in the air and stores the data. The P-Trak UPC can deliver data in real time, providing information on the lowest, average, and highest pollution concentration over a span of time. Pollutant concentrations have a high variance over short periods of time and requires longer measurement times for greater accuracy. While it is necessary to take many measurements during the rush hour times in Østerbro, it is also necessary to maintain high data integrity, and the number of measurements is therefore limited by the required accuracy of data. This makes it prudent to create an estimate time standard spent for measurement collection, one of the initial goals upon reaching Denmark.

Our team estimates that each measurement will take half an hour, 20 minutes to measure and 10 minutes to move to the next area of measurement. The time spent measuring will be further broken down into five minute segments, each of which will produce high, low, and average data points. These points will be recorded on a physical medium along with date, time and location. The full set of real time data will be stored on the UPC. To more accurately estimate the time available, our team must consider rush hour length, rain days and Danish holidays. In the planned four week measurement period, there will be approximately 20 days where it is possible to measure rush hour pollution. It is likely that it will rain on some of these days, and the P-Trak device is unable to take measurements while raining. Our team estimates one rain day per week, based upon past weather in Copenhagen. The number of days can be converted into a more useable format by multiplying by the hours of rush hour a day, which gives around 60 hours of rush hour measurement. At this time, our estimated number of rush hour measurements is approximately 100. The estimation is low, considering the amount of spatial data that needs to be recorded. This necessitates multiple groups for each measurement time, with each group measuring at a different area, to increase the total number of measurements possible to 200. This effectively doubles the area that can be covered and will help to increase the accuracy of pollution data.

While our team will attempt to take as many measurements during rush hour, time is too limited to take all the measurements desirable. There is still a need to measure other roads that might not be so heavily affected by rush hour traffic. These roads are critical to establishing the baseline pollution levels in Østerbro and will likely serve as the alternate walking and cycling routes through the district. This makes mapping the small roadways just as important as the main roadways. During the initial weeks of being in Copenhagen, if our team finds minimal difference in pollution on side roads between rush hour and off-peak times, it becomes possible to generalize measurements taken during off-peak times. Measurements taken during off-peak times will allow for a better baseline pollution level, as well as establishing what routes are already predisposed to high pollution levels.

Once finished with measurements, our team will then prepare the data into an interpretable form. This mainly constitutes taking the data stored on the UPC, and uploading it to a computer. This data, along with location and date are stored electronically, as explored in section 3.3.

3.3 Visualization of Data and Routes

Our goal is to help people use the information we gather; properly displaying our information is critical to the success of our goal to improve the health of Østerbro citizens. Not only must we display the information we gather, but we must also display the information using a user-friendly graphical user interface. Using maps, that can show the routes with the lowest concentration of pollution, and charts, that can show more precise data, users will be able to understand not only which routes are safest, but also the differences in pollution concentration of multiple areas.

3.3.1 Digital Organization of Data

In order for our project to effectively communicate the knowledge of which routes have the lowest concentrations of pollution, we will put the information into a database accessible by a web page. The webpage needs to utilize the database without slowing down, requiring the stored information to be organized in an efficient and easily accessible manner. The database will hold information on the more precise, raw, five minute data for the purpose of charts. The database will also hold analyzed data from the collection of five minute intervals. The data can either be analyzed by hand or through software, if software is available. The webpage could create the analyzed data from the raw data without using a database; however, if the webpage were to recreate this information every time it ran, the webpage would lag, impacting user friendliness. In order for the database to run efficiently and hold all the information we require, we will originally compose the database with two tables: raw data and analyzed data. After further contact with the sponsor the suggested tables may change to better fit the sponsor's finalized needs.

It is unlikely that we will use the raw data in the heat map, but instead we will use this raw data for visualizing pollution on a road over time in the form of a chart. The table for raw data will likely contain six records. Two of the records will be used to denote a starting and ending location. We will separate each street into nodes and named as a concatenation of the street name and the assigned node number. We will determine the number of nodes based on the number of intersections with other streets and the amount of data we have on that street. Another record represents the date and time at which the measurement began and is assumed to last five minutes from that point. The remaining three records are for the actual data from the five minute interval; representing the lowest, average and highest concentration of pollution in number of particulates per cubic centimeter.

We will use the analyzed data for the heat map. The table for analyzed data will likely contain six records. The first two records are the location records and are the same as the raw data table. The next record is the physical distance in kilometers between the two location nodes. The remaining three records are the analyzed data on total average pollution before, during, and after rush hour in number of particulates per cubic centimeter. An alternate design for this table would be to have a variable denoting which time frame the measurement was taken during. This would create three times the number of records in the database and require a much more complex database query in order to receive the desired information. There would not likely be a noticeable difference in webpage performance between the two designs; as such, we have selected the first option as it is easier us to input the information with less duplication, and accessing the information is logically easier.

3.3.2 Heat Maps and Graphs

We have chosen to use heat maps and graphs to display our information. Some variation of the heat map, denotation of lows, highs, and everything in between using color, is the only way to display rastered spatial information in a visually pleasing manner. The heat map will provide a visual comparison between low pollution concentrations and high pollution concentrations, and where those areas exist in the Østerbro district. We can successfully create a heat map on a webpage by taking the information from the analyzed data table and using an open source javascript (js) library. One js library we can use is Heatmap.js, provided by Patrick Wied under an open source MIT license (Wied). The open source MIT license allows use by a third party provided the author is credited for their work. A sample heat map is shown in Figure 3.b. Heatmap.js will interface easily with our database, requiring an x and y location value and a weight for each data point. The x and y location can be extrapolated from our database using the database records about location. The weight value can be

Figure 3.b: An example of a heat map overlaying a city (Wied).

directly taken from our pollution records with little to no manipulation. Heatmap.js represents the lowest weight with a coolest color, dark blue, the highest weight with the warmest color, red, and any middle values are assigned a heat of color based on their relation to the highest and lowest weights. Another potential option is the js library called Raphaël. Raphaël would be ideal as it would allow for specific data to appear on mouseover of the desired road; however, Raphaël requires a Scalable Vector Graphic (svg) of the Osterbro district (Raphaël). We have yet to find any such graphic, rendering Raphaël useless.

For more precise pollution data, our project will use graphs comparing concentrations of particulates across time. Similarly to heatmaps, implementing graphs will require the use of an open source JavaScript (js) library. One library we may use for creating our graphs is called the JavaScript InfoVis Toolkit (JIT), written by Nicolas Garcia Belmonte under an MIT license (Belmonte). The JIT allows for stacked area graphs, providing us the opportunity to display the lowest, average, and highest concentrations taken from our raw data table in a single graph. An example of a stacked area graph is shown in Figure 3.c. The JIT takes in a name for the chart, the name for each separate section of the chart, and any number of values to display for each section (Belmonte). Another option is the jQuery Visualize library ("JQuery Visualize," 2013). This takes in all the same information as JIT and is merely visually different. Which one we will select for our data will be entirely stylistic with input from the sponsor. As our reach goal, we would like to allow for selection between any set of nodes and have the graph update accordingly. This dynamic functionality will create an interactive and informative web page.

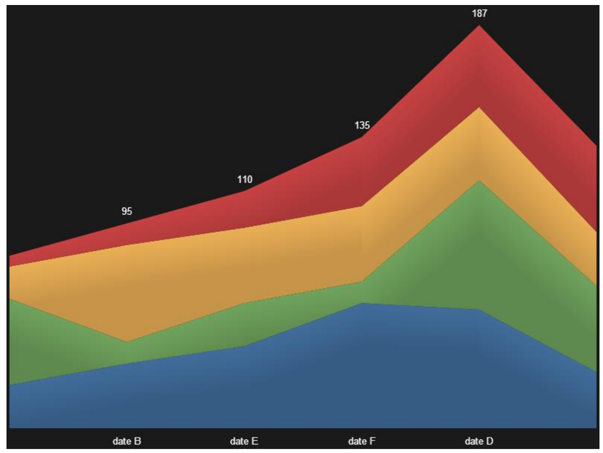

Figure 3.c: An example of a stacked area graph (Belmonte).

3.4 Discerning Safer Routes

For our project, we will define safer routes and times of day using two criteria. We will use guidelines set by the World Health Organization (WHO) to determine if any routes or locations exceed current pollutant concentration guidelines. We will compare collected data to itself to identify the least polluted routes and what times of the day are least polluted near parks and kindergartens. These criteria in combination with the visualization method discussed in Section 3.3 will be used to determine which routes pose the smallest risk to Østerbro residents.

3.4.1 Raw Data Analysis

WHO European Regional Office sets guidelines for outdoor air pollution and constantly revises and updates them. The 2005 Global Update includes information and guidelines specific to particulate matter, ozone, nitrogen dioxide and sulfur dioxide. These standards aim to encourage the reduction of known pollutants that are hazardous to human health and are presented in Table 2.3 Using WHO's guidelines, the European Union in 2008 set objectives and target dates to reduce the population's exposure to fine particulate matter ($PM_{2.5}$) and maintain limits of coarse particulate matter (PM_{10}) concentrations ("WHO outdoor air quality guidelines," 2014). Particulate matter can cause adverse health effects at any concentration. The threshold set by WHO is the level at which the smallest amount of adverse health effects occur. Our project will use these guidelines to determine which areas, if any, exceed these concentrations and if they should be avoided.

As described in Section 3.2, we will take measurements before, during, and after rush hour traffic times. We will compare these measurements and analyze them in relation to each other to determine if any differences exist and if these differences will have a significant impact on Østerbro resident's health.

3.4.2 Determining what makes a Route Safer

The thresholds and guidelines provided by WHO will not be primarily used to determine which routes are safer. While these thresholds are ideal to reach, our project is not focusing on changing current pollution concentrations. We will compare the measured pollutant concentrations to each other to determine which routes are safer. After comparison, we will deem the route or routes with the lowest average pollution concentration to be considered safer, and we will label the route or routes with the highest concentration of pollution to be the least desirable route(s). We will do a similar comparison at different times throughout the day near parks and kindergartens.

3.5 Conclusion

Air pollution concentrations can have a large, negative impact on the overall health of Østerbro residents. These health effects can be lessened by reducing direct exposure to pollution sources. This project aims to provide new routes through the Østerbro district in order to help residents avoid vehicular sources of pollution. Other potentially positive effects include a reduction in vehicular traffic by encouraging safe pedestrian travel. The proposed methodology and accompanying research will allow our team to provide Østerbro residents with the knowledge to positively change their habits to improve their overall well-being.

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