ERASMUS UNIVERSITY ROTTERDAM – Erasmus School of Economics

Bachelor Thesis Urban, Port and Transport

Quantifying the health effect of Rotterdam's sustainable transport transition: mortality rate and health costs

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Final version handed in on October 28, 2020

Abstract

This paper quantifies the health benefits and savings in health costs of a transition of 17,000 car trips per day to bicycle and public transport within Rotterdam, a goal formulated by the *Rotterdamse Mobiliteits Aanpak*. This will be done by looking at three stressors: exposure to air pollution, physical activity and fatal traffic accidents. Data used for the analysis comes from past research done and is retrieved from several datasets provided by Centraal Bureau voor de Statistiek. By calculating the relative risks on mortality rate for the different transportation modes for each stressor, the number of deaths saved, and life years gained for different age groups can be quantified. This results in a number of life years saved ranging from a loss of three days due to an increase in exposure to air pollution to a gain of one month and 26 days due to the increase in physical activity, with potential savings that range from € 11,271,951 to € 66,965,854 in health costs. It can be concluded that the mobility shift would have a positive effect on all-cause mortality rate and health costs for the citizens of Rotterdam due to the large impact of the increase in physical activity. This positive effect is reduced by the increase in exposure to air pollution and there is almost no change in fatal traffic accidents. The shift of 17,000 car trips per day formulated by the *Rotterdamse Mobiliteits Aanpak* would be positive for the travelers making this shift and the health costs of Rotterdam.

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1. Introduction

Cities all around the world are constantly trying to become more environmentally friendly. One of the main measures taken by these cities often involve a reduction in car usage. In 2003, London introduced the London Congestion Charge (CC). It was the first city to raise such a large scale pricing scheme. The London CC charges cars and motor vehicles that want to drive through the city center of London from 7 am till 6:30 pm (Santos & Shaffer, 2004). This measurement reaches several goals of the government as it reduces traffic flow in the city streets, as well as air pollution and noise disturbance. Hereafter, several cities such as Valletta (2007), Stockholm (2007), Milano (2008) and Gothenburg (2013) also introduced pricing schemes in their city centers, aiming to reduce the car use (Eliasson & Royal, 2014).

Following these world cities, the city government of Rotterdam is quite involved in making Rotterdam more environmentally friendly as well. This is a big challenge for a city that has been growing as much as Rotterdam has. Currently, its number of citizens is at 651,376 and this has had a percentual increase of 9% each year for the last 5 years (Alle cijfers, 2020). Such an increase challenges the city government to, on the one hand, let the city grow and keep the economy and distribution processes alive, and on the other hand, keep the living circumstances for its citizens acceptable. In order to do this, Rotterdam's city government has formulated a mobility plan called the *Rotterdamse Mobiliteits Aanpak (RMA)* (Gemeente Rotterdam, 2020).

In the RMA, the city government has established nine goals for the coming years until 2040. The first goal is to make a mobility transition in which most people in the city center will substitute the use of car transport to public transport, cycling and walking. In this research, these modes of transport will be referred to as the sustainable transport modes. The goal with this is to make the city center cleaner and more hospitable. Another important goal is to create a coherent public transport network within Rotterdam. With better connections between Rotterdam North, West, East and South, the citizens have a higher probability of travelling within Rotterdam using sustainable modes. (Gemeente Rotterdam, 2020)

In the short run, there are several measures that are taken in order to achieve these long term goals. First of all, the city government has started the reconstruction of the Coolsingel. There will be a reduction of two lanes for cars and motor vehicles with which they want to create a wide pedestrian precinct and wider and safer lanes for bicycles (Het Project, 2016). Next to that, they are improving the public transport infrastructure in order to decrease short drives within the city center. Moreover, parking spots on the street will be replaced by walking routes in order to stimulate walking and cycling.

One of the coordinating goals, which all aforementioned measures help working towards, is a healthier city. From a health perspective, these measures should increase air quality, decrease noise inconvenience, increase safety, and social participation. Indicating that if the city's air quality increases and noise disturbance decreases, its citizens are less likely to have respiratory complaints, heart and vascular diseases and sleep disturbance. This will eventually result in better general level of health of the population of Rotterdam (Gemeente Rotterdam, 2020). The aim of this research is to quantify these potential health benefits of the mobility transition for the citizens of Rotterdam.

There are several studies that have quantified the health benefits of the sustainable mobility transition. De Hartog et al. (2010) in their article *Do the Health Benefits of Cycling Outweigh the Risks?* did a study in the Netherlands on the transition from car to bicycle for 500,000 short trips. Their research resulted in the claim that the health benefits that were estimated from the use of bicycles would clearly outweigh the risks related to car driving for individuals that shifted their mode of transportation. Additionally, Lindsay et al. (2011) modeled the effects of varying percentages of vehicle kilometers travelled by bicycle instead of cars and got to the same conclusion: the health benefits are significantly larger while using the bicycle and it outweighs the risk of road injuries.

It has been proven that a transition towards usage of public transport and cycling has a positive effect on health. It, however, has not yet been quantified and tested for the city of Rotterdam. This paper's research question will therefore be:

To what extend will the replacement of car transport by cycling and public transport have an effect on all-cause mortality and health costs for the citizens of Rotterdam?

In order to answer this research question, first, prior research done on the effect of air pollution, physical activity, and fatal traffic accidents on mortality rate will be reviewed. This will follow in the conceptualization of the framework for Health Impact Assessment (HIA) introduced by Joffe and Mindell (2002). Hereafter, past research done on quantifying the effect of such transport policies will be discussed. This will be followed by the methodology and the analysis will be explained more thoroughly in which several scenarios will be formulated. These scenarios are based on the goals formulated by the *Rotterdamse Mobiliteits Aanpak* and this research will also consider scenarios in which these goals are not fully met. The scenarios differ in numbers of reduced trips and types of replacement transport modes (cycling, public transport or both). For each scenario, the effect of the increase in air pollution exposure, physical activity, and risk of fatal road accidents on all-cause mortality will be measured. Eventually, for each of these scenarios, a change in mortality rate and health costs for Rotterdam will be presented. This study will conclude with a discussion on the used methods and retrieved results, as well as suggestions for future research and an answer to the research question.

2. Theoretical Framework

2.1. Health Impact Assessment

The aim of this research is to quantify the effect of the sustainable mobility transition goals formulated in the *Rotterdamse Mobiliteits Aanpak* by estimating a change in mortality rate for Rotterdam and a change in health costs accompanying this. The conceptual framework used for this follows the Health Impact Assessment (HIA) introduced by Joffe and Mindell (2002). A HIA in general is a way of assessing the potential health impact of a policy or project on a population (mostly disadvantaged groups) and often results in recommendations that can be formulated with the aim of maximizing the positive health benefits (WHO, n.d.). In their paper, Joffe and Mindell (2002) establish a policy risk assessment model (PRAM) in which they enable the comparison of different policy outcomes. The PRAM introduces a framework which can relate the change of level of exposures or risk factors to changes in health. This approach is suggested to mainly use in the context of assessing results of policies to a change in health status. Since the *Rotterdamse Mobiliteits Aanpak* is a policy from the government of Rotterdam, this is a suitable method to base the conceptual framework used in this research on.

In their HIA, they suggest to make a conceptual framework which specifies the different types of health effects that are specific for the policy (Joffe & Mindell, 2002). The diagram from transport policy to health outcomes formulated by Joffe and Mindell (2002) contains several consequences of a reduction of car trips in a city. The consequences mentioned are the decrease in emission of air pollution, increase in physical activity, decrease in noise disturbance and increase in the social use of the outdoor spaces which would increase someone's mental health. Additionally, they mention the change in road injuries and community severance.

Based on previous done research, this paper will only consider the changes in exposure to air pollution, physical activity and changes in fatal road traffic accidents as stressors that affect the health of the Rotterdam citizens by replacing car trips by public transport and bike transport. Previous research done on these stressors and their relation to all-cause mortality and the reason as to why these stressors are chosen to investigate in this paper will be discussed more thoroughly in the coming paragraphs.

2.1.1. Exposure to air pollution and all-cause mortality

Replacing car trips by bicycle and public transport trips will cause a change in exposure to air pollution. Kaur et al. (2007) confirms this by claiming that both driving and cycling can result in a higher exposure to air pollution compared to regular urban background concentrations. There has been a lot of research done on the change in exposure to air pollution and its relation on all-cause mortality. As Cepeda et al. (2017) shows, already a total of 4,037 studies are carried out on this particular topic. According to de Hartog et al. (2010), most of the recent studies on this matter have focused on fine Particulate Matter (PM) as measure of air pollution since it has been proven that PM is the air pollutant that is most related to human health effects. This research will therefore focus on the following air pollutant: $PM_{2.5}$. $PM_{2.5}$ is an air pollutant that has a diameter of 2.5 or less micrometers. It reduces visibility and can cause the air to seem hazy when the level increases (EPA Victoria, 2019). The fact that sustainable mobility transition would lead to a higher exposure to $PM_{2.5}$ and that it has been proven that exposure to $PM_{2.5}$ has a significant effect on health leads to the first sub-question:

1. What is the effect of a change in exposure to air pollution ($PM_{2.5}$) due to change of car trips to bicycle and public transport trips on the mortality rate of Rotterdam?

Looking at the research done on the effect of $PM_{2.5}$ on health and mortality, the following is found. According to Pope et al. (2002), the risk of getting lung cancer and cardiovascular disease (CVD), and therefore mortality, increases with the amount of exposure to $PM_{2.5}$ from air pollution. They claim that there is not a linear relationship but that there is a steep increase in risk at low exposures and then this flattens out for higher exposures. Consequently, even short exposures to air pollution is likely to affect the mortality rate (Pope et al., 2002). Additionally, Janssen et al. (2013) did research on the daily mortality rates in the Netherlands and various PM size fractions. They found that $PM_{2.5}$ is significantly associated with mortality (Janssen et al., 2013). Due to the information generated from this past research, this paper will hypothesize the following:

The increase in exposure to air pollution due to the change from car trips to bicycle and public transport trips will lead to a higher mortality rate for the citizens of Rotterdam.

2.1.2. Physical activity and all-cause mortality

The second stressor in change in mortality rate due to the sustainable mobility transition is the increase in physical activity. It has been proven by several researchers that there is a relationship between physical activity and mortality. Warburton et al. (2006) confirmed that regular physical activity has an evidential effect on primary and secondary prevention of several chronic diseases. Some examples of these chronic diseases are diabetes, cancer, depression, and obesity. Additionally, Bauman (2004) confirms that recent evidence shows that a moderate level of physical activity decreases the probability of getting cardiovascular diseases and all-cause mortality. A moderate level of physical activity in this paper indicates about half an hour for most days of the week. Furthermore, Kesaniemi et al. (2001) determined that there is a linear relationship between physical activity levels and all-cause mortality. It is therefore safe to say that there is evidence on physical activity having a positive impact on mortality rate, which leads to the following sub-question:

2. What is the effect of a change in physical activity due to change of car trips to bicycle and public transport trips on the mortality rate of Rotterdam?

Only a few studies focused on reporting health benefits from cycling. However, several findings of research done on cycling to work is reported by Andersen et al. (2000), Hu et al. (2004), and Matthews et al. (2007). Andersen et al. (2000) evaluated the effect of different levels of physical activity during leisure time, sports, and cycling to work on all-cause mortality. Looking specifically at the effect of cycling to work, even after adjustment of other risk factors (e.g. leisure time activity), the people who did not cycle to work, faced a higher mortality rate of 39% than the people who did cycle to work. Furthermore, Hu et al. (2004) researched the effect of walking or cycling to and from work on risk for Type 2 diabetes. He found that an increase in the daily time spend on this active commuting was inversely related to the relative risk of Type 2 diabetes. Lastly, Matthews et al. (2007) did research on the influence of cycling on mortality in Chinese women. In order to evaluate the influences of cycling as mode of transportation, they fit models that controlled for other types of physical activity during the day. Cycling for transportation can be concluded as having an inversely and independently significant effect on all-cause mortality. Using the information from these three studies, this research hypothesizes the following:

The increase in physical activity due to the change from car trips to bicycle and public transport trips will lead to a lower mortality rate for the citizens of Rotterdam.

2.1.3. Fatal traffic accidents and all-cause mortality

In 2004, road traffic injuries are the 11th leading cause of global deaths, accounting for 2% of all global deaths (WHO, 2004). In the Netherlands, in 2019, there were 661 deaths due to fatal road accidents, this number has decreased with 2.5% compared to 2018, in which there were 664 deaths due to fatal road accidents. A little over one thirds of these traffic deaths are car drivers (237) and a little less than one thirds are cyclists (203). Looking at distribution of deaths for different age groups, in 2019, 38% of the traffic deaths were 70 years or older and only 2% of the victims were between 0-14 years old. (SWOV, 2020). Additionally, looking at deaths in public transport, according to SWOV (2011), there was only one traffic death due to traveling with public transport. This raises the last sub-question:

3. What is the effect of a change in fatal traffic accidents due to change of car trips to bicycle and public transport trips on the mortality rate of Rotterdam?

Looking at the numbers mentioned by SWOV, it can be concluded that the percentages of traffic accidents between cars and cyclists are relatively equal. On the other hand, there are a lot less fatal traffic accidents while traveling with public transport. This research therefore hypothesizes the following:

The increase in fatal traffic accidents due to the change from car trips to bicycle and public transport trips will lead to a lower mortality rate for the citizens of Rotterdam.

2.1.4. Conceptual framework

As mentioned before, in their Health Impact Assessment, Joffe & Mindell (2002) suggest making a conceptual framework which specifies the different types of health effects that are specific for the policy. Based on the relations mentioned before, in this research, the health effects of replacing car trips by public transport and bike transport are the changes in exposure to air pollution, physical activity, and changes in road traffic fatal accidents. The map of the conceptual framework that will be used in this research is shown in Figure 1. As earlier mentioned, there are several other consequences resulting from the sustainable transport policy that could possibly impact health. These factors will also be present in the situation here in Rotterdam, but they will not be considered in this research.

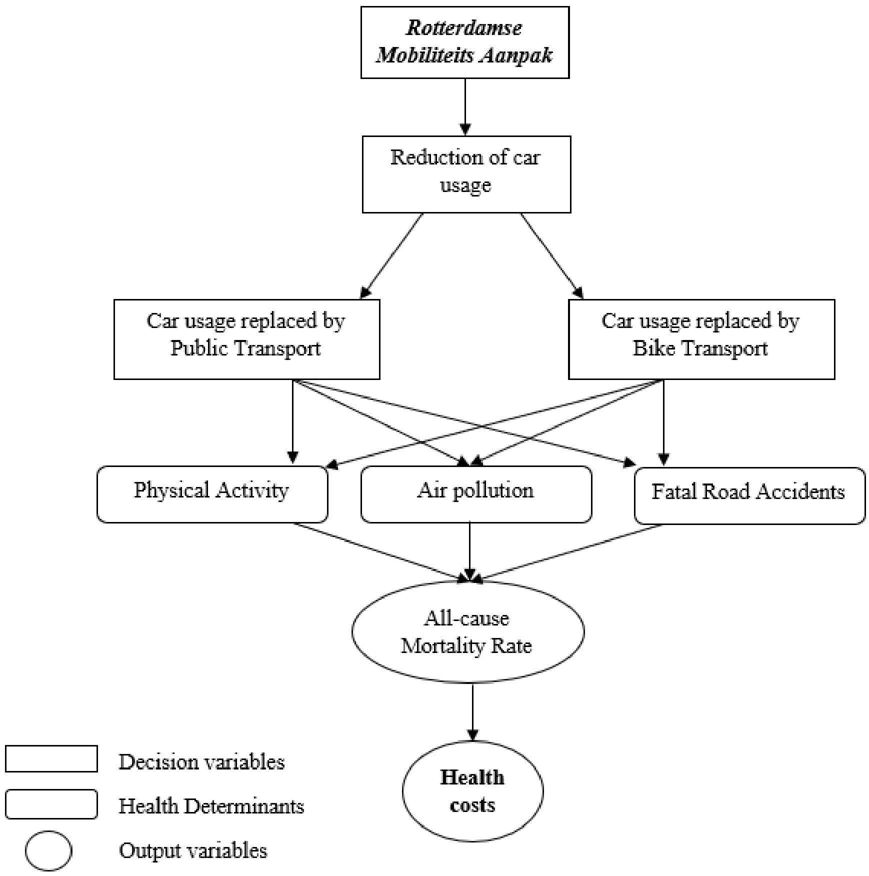

Figure 1. Conceptual framework for the Health Impact Assessment on the *Rotterdamse Mobiliteits Aanpak*

2.2. Previous research

The health benefits of the sustainable mobility transition has been quantified and captured several times in previous studies. This section will elaborate more on these past studies and their similarities, differences and findings. Eventually, this will result in a comparison with this research.

De Hartog et al. (2010) quantified the impact of 500,000 Dutch citizens changing from car to bicycle for short trips (7.5 km / 30 min) in the Netherlands. The three stressors used in their research are air pollution (considering $PM_{2.5}$ and the decrease in overall level of air pollution), physical activity, and traffic accidents (both fatal and severe injuries). For each stressor, the relative risk of change in transport mode is calculated. Eventually, using standard life table calculations, they were able to quantify change in mortality rate. The effects of increased physical activity are substantially larger (3-14 months) than the effects of increased inhaled air pollution (0.8-40 days lost) and increase in traffic accidents (5-9 days lost), concluding that the benefits of the active mobility transition outweigh the risks. (De Hartog et al., 2010)

A similar research has been carried out by Lindsay et al. (2011), who estimated the effect of the change from motor car to bicycle for short trips (≤ 7 km) on three stressors: health, air pollution and greenhouse gas emissions in New Zealand. For their estimation, they made use of several models: HEAT, Vehicle Emission Prediction Model (VEPM) and Health and Pollution in New Zealand (HAPiNZ). Their results show that shifting 5% of vehicle kilometers in New Zealand to cycling, 116 deaths would be avoided annually resulting from physical activity, six deaths would be avoided due to a decrease of local air pollution and five deaths would be added due to cyclist fatalities. It would save New Zealand about $200 million per year. (Lindsay et al., 2011)

These two studies have only captured the effect of changing from car transport to bicycle transport. Likewise, the effect on health and economic factors from replacing car by public transport has been investigated. Two studies capturing the consequences of this shift are Rojas-Rueda et al. (2012) and Edwards (2009). Rojas-Rueda et al. (2012) quantified the health benefits of changing mode of transport from car to either bicycle or public transport for 20 and 40 percent of the trips in the city of Barcelona. In their research, they investigated air pollution (considering both exposure to $PM_{2.5}$ and PM_{10} and decrease in overall level of air pollution), physical activity and fatal road traffic accidents. They were able, using the Barcelona Air-Dispersion model, to quantify the exact decrease of concentration of $PM_{2.5}$ in the air of the city center. Additionally, they used the HEAT tool for the estimation of the effect on physical activity. In general, they found that the active mobility transition would generate health benefits for travelers and for the general population of the city. (Rojas-Rueda et al., 2012)

The second study capturing the health benefits of taking public transport is done by Edwards (2008). He was able to describe the health benefits of taking public transport as it is assumed that while making this transition, people on average would walk 8.3 more minutes per day. According to Edward (2008), this would save $5,500 per person in present value due to a reduction in obesity-related medical costs.

These examples of past research done on quantifying the health benefits of the mobility transition relate to each other in the sense that they all take air pollution, road traffic accidents and physical activity as their main indicators for health. Both De Hartog et al. (2010) and Lindsay et al. (2011) only did research on the transition from car driving to bicycle. Rojas-Rueda et al. (2012) and Edwards (2008), however, were able to conclude that there are also health benefits coming from a transition from car driving to public transport due to an increase in walking to and from the stations.

This research stands out from previous research done as this research will consider health effects of transitioning from car trips to both bicycle trips as well as public transport trips. Furthermore, the quantifying of health benefits from the sustainable mobility transition have never been estimated for the city of Rotterdam specifically. Since the recent policy formulated by the city government (*Rotterdamse Mobiliteits Aanpak)*, this research is quite a modern topic. Lastly, previous research not always captured the change in health costs. This research plans on estimating this for the city of Rotterdam as well.

3. Data & Methodology

3.1. Data

3.1.1. Exposure to air pollution

Several types of data are needed in order to estimate the effect of the change in exposure to air pollution on the change in mortality rate namely data on minute ventilation and exposure to air pollution for the different activities. Data on minute ventilation will be retrieved from research done by Rojas-Rueda et al. (2012). Additionally, data on the different exposures in air pollution for different types of transport will be retrieved from research done by De Hartog et al. (2010) and Cepeda at al. (2017).

De Hartog et al. (2010) gave an overview of car/cycle exposure to air pollution ($PM_{2.5}$) ratios found in different articles, this overview is provided in Table A1 (Appendix). Cepeda et al. (2017) extracted the average exposure and inhaled dose from 39 different articles which they used to formulate ratios in exposure to air pollution for the different types of commuters. An overview of all results provided by Cepeda et al. (2017) on $PM_{2.5}$ is provided in the Appendix, Table A2. As Table A2 shows, there are two numbers for the cyclists/car ratio: regular car and car with controlled ventilation settings. Since almost 99% of the new cars are provided with controlled ventilation settings (Motor Trend Staff, 2010), this ratio will be used. Furthermore, Cepeda et al. (2017) made a distinction between public transport with the bus and Massive Motorized Transport (MMT), under which metro, tram, and train fall. This research will use the ratios provided for MMT since this ratio capture the most complete picture of air pollution exposure in public transport.

3.1.2. Physical activity

For the estimation of the effect of an increase of physical activity, past articles doing research on the comparison between of all-cause mortality of commuting by bike/walking instead of car will be used. De Hartog et al. (2010) estimates the potential impact of physical activity on all-cause mortality by summarizing different studies. Studies included in this overview are Andersen et al. (2000), Hu et al. (2004), and Matthews et al. (2007).

3.1.3. Fatal traffic accidents

For the estimation of the effect of a change in road traffic accidents several datasets are needed. First, the percentage of traffic participants per age category for each mode of transport (car, bicycle, walking and public transport) is retrieved from the database *Personenmobiliteit; persoonskenmerken en vervoerwijzen, regio, 2010-2017* provided by Centraal Bureau voor de Statstiek (CBS). This database provides information on the total number, distance and duration of trips per mode of transport per person per year over the years 2010-2017 per region. Furthermore, the all-cause mortality rate per age group needs to be retrieved from CBS as well. The data used for this comes from a combination of datasets: *Overledenen; doden door verkeersongeval in Nederland, wijze van deelname* provided by CBS, *Overledenen; doden als gevolg van verkeersongeval in Nederland, provincie* provided by CBS, and lastly, *Totale reizigerskilometers in Nederland per jaar; vervoerswijzen*, regio's provided by CBS.

3.1.4. Population

Data on the population of Rotterdam is necessary for the final part of the analysis. The calculation starts with the number of inhabitants in Rotterdam which will be retrieved from the database called *Bevolking op 1 januari en gemiddeld; geslacht, leeftijd en regio* provided by CBS. This database is able to provide the number of inhabitants of the municipality Rotterdam on the 1st of January 2020 for every age. Additionally, the number of deaths per age category of the municipality of Rotterdam needs to be known. This data will be retrieved from the database called *Overledenen, geslacht, leeftijd, burgerlijke staat, regio* provided by CBS. Table A3 in the Appendix shows the distribution and age groups used in this study.

3.2. Methodology

3.2.1. Different scenarios

The *RMA* quantifies several goals they want to reach by 2040. In absolute numbers they want to decrease the car usage in the city center of Rotterdam with 17,000 trips per day. Additionally, they want to increase the number of bike trips with 67,000 trips and the number of public transport trips with 52,000. In order to give an indication of the totals, by 2040, according to the *RMA*, Rotterdam should have 188,000 bicycle trips per day and 50,000 car trips per day (Gemeente Rotterdam, 2020).

In this research, different scenarios of reduction in car usage will be analyzed. These scenarios consider the goal of a reduction of 17,000 car trips per day the *RMA* mentions and uses this as a starting point. In scenario one, the reduction of 17,000 car trips per day is completely substituted by bike transport. In scenario two, the reduction of 17,000 car trips per day is completely substituted by public transport. In scenario three, 50% of this reduction is by bike transport and 50% of this reduction is by public transport. The same proportion of replacement is done in scenario four and five, however with a lower reduction of car trips: 12,000 and 7,000 per day, respectively. These last two scenarios will be considered as it is possible that less car trips will be replaced than expected by the *RMA.* An overview of the scenarios is represented in Table 1.

Table 1. Different scenarios analyzed in this study, showing the reduction of car trips and by which transport mode the trips are replaced

Scenario **Number of**	**1**	**2**	**3**	**4**	**5**
Car trips reduced per day	17,000	17,000	17,000	12,000	7,000
Trips replaced by bike transport	17,000 (100%)	0	8,500 (50%)	6,000 (50%)	3,500 (50%)
Trips replaced by public transport	0	17,000 (100%)	8,500 (50%)	6,000 (50%)	3,500 (50%)

This research assumes that the car trips that are replaced are 30-minute trips (7.5 km). This distance and time duration of the trip is chosen as trips within Rotterdam have a maximum of 7.5 kilometers, which is a half hour bicycle trip. Additionally, it is realistic to assume that car trips of 7.5 km can be replaced by bike trips that last half an hour. Furthermore, this research will assume that there is a 10 minute walk to the station involved in traveling with public transport.

3.2.2. Conceptual Framework

This research will calculate the potential change in mortality rate due to the mobility transition using the conceptual framework presented in Figure 1. In order to understand the methodology used, it is helpful to start at the end of the analysis. As the Figure 1 shows, the final step is to estimate the change in health costs due to the change in mortality rate. This change in mortality rate results from the relative risks that are related to traveling with public transport and bicycle compared to travelling with the car. The intensity of these relative risks differ for each stressor and each scenario. The following paragraphs will show the methodology used in this research, starting at the final steps of the analysis, and working back to the start.

3.2.2.1. Health costs

As Figure 1 shows, the last step of the analysis is the estimation of the change in health costs for the city of Rotterdam. This will be done using the Value of Statistical Life (VSL) (WHO, 2019), which estimates the average value of a life year using the willingness to pay of individuals to reduce their chances of death. Differently put, this indicates the amount someone is willing to pay in order to stay alive. This results in being able to calculate the change in health costs by multiplying the VSL by the change in number of deaths following the formula:

$$\Delta Health\ costs = VSL * \Delta\ deaths \tag{1}$$

From this equation it follows that the change in number of deaths, equivalent to mortality rate, due to the mobility transition needs to be established. The approach to get the number of deaths saved due to the mobility transition is further explained in the following paragraphs.

3.2.2.2. Mortality rate

In order to find the change in mortality rate, standard life table calculations (Miller & Hurley, 2003) are used. The standard life table calculations start with the entry population and number of deaths for each age category. The age categories used in this research are 18 - 25, 25 - 35, 35 - 50, 50 - 65, 65 - 75, and 75 and older. The ages below 18 years old will not be considered as they are not able to make the mobility transition since they are not allowed to drive a car yet. Moreover, these specific categories are chosen since the database provided by CBS on yearly number of deaths in the city of Rotterdam provided these age categories. The estimation for the scenario with no change in mode of transport will be the baseline to which each scenario will be compared.

Once the number of people p and number of deaths d per age group are retrieved, these will be used in order to calculate the hazard rate h ($h = d/p$). This is also defined as the "instantaneous probability of death at a particular time, conditional on having survived to that time" (Miller & Hurley, 2003). This hazard rate will then differ per scenario, stressor and age group and will be used with standard life table calculations in order to calculate the number of people from the current population that would still be alive after 82 years – the average life expectancy of a citizen of Rotterdam (CBS Doodsoorzakenstatistiek, 2019). Hereafter, for each scenario, age group and stressor, the relative risk will be used to update the hazard rate and calculate the new number of deaths. Table A4 in the Appendix shows the baseline number of deaths which refer to the number of deaths that would have taken place if nobody were to change their mode of transport. Each scenario will be compared to these numbers.

Additional to the number of deaths saved, it is also interesting to calculate the life years per person that would be gained or lost in each scenario, compared to the normal circumstances (with no transition from car trips to sustainable transport modes). The gain in life years is a concept in health economics which indicates the number of additional years that a person would live, as a result from a specific treatment. In this case, that treatment is transitioning from car transport to a sustainable mode of transport. The gain in life years for each age category follows from the following formula:

$$Gain\ /\ loss\ in\ life\ years\ _{age\ category} = \frac{\#\ deaths\ saved\ per\ year_{age\ category}}{\#\ people_{age\ category}} * 365\ days \quad (2)$$

The following paragraphs elaborate more on how the relative risks for each stressor that are needed to change the hazard rate for each scenario are estimated for each stressor separately.

3.2.2.3. Exposure to air pollution

An increase in cycling and walking outside will increase the amount of emission a person is exposed to. For the analysis of the relative risk on mortality rate of an increase in exposure to air pollution several steps are taken. First, the inhaled dose per day needs to be estimated. Afterwards, this will result in an equivalent change in exposure to $PM_{2.5}$ which will result in a relative risk on mortality rate. The steps explained in the following paragraphs are followed for each scenario. Scenarios 3, 4 and 5 will result in the same as they all include a change of 50% public transport and 50% cycling. They will therefore be taken together in this part of the analysis.

As abovementioned, the inhaled dose of $PM_{2.5}$ per day needs to be estimated. In order to do this, minute ventilation per mode of transport and activity, concentration of exposure to $PM_{2.5}$ per mode of transport and activity and duration of each activity per day is needed and will follow from the following formula:

$$Inhaled\ dose\ (\mu g/day) = duration\ (h/day) * minute\ ventilation\ (L/h) * concentration\ (\mu g/m^3) \quad (3)$$

In order to only find the effect of the change in mode of transport, it will be assumed that a person sleeps 8 hours per day, travels for 30 minutes per day and is in rest for the rest of the day (15.5 hours).

The minute ventilation is expected to variate between the different modes of transport as someone who cycles or walks experiences a higher minute ventilation. Rojas-Rueda et al. (2012) showed the following ratios of minute ventilation for different modes of traveling: [bike, walk, car, bus, metro, rest] = [6, 4, 1, 1, 1, 1]. This is calculated using algorithms developed by the United States Environmental Policy Agency (EPA) and performed on a random population distribution (Johnson 2002; De Nazelle et al. 2009). Lastly, according to de Hartog et al. (2010), the minute ventilation ratio at sleep and rest is assumed to be 1:2 on average.

Using the average minute ventilation in rest of 6 liters per minute formulated by Benumof (2012), the minute ventilation while sleeping, in rest and during different modes of transport can be calculated. This will result in the following: 3 l/min (0.18 m^3/h) while sleeping, 6 l/min (0.36 m^3/h) in rest, while driving a car and traveling with public transport, 24 l/min (1.44 m^3/h) while walking and 36 l/min (2.16 m^3/h) while cycling.

Lastly, the concentration of $PM_{2.5}$ someone is exposed to affects the inhaled dose of $PM_{2.5}$. According to de Hartog et al. (2010), the concentrations of $PM_{2.5}$ during sleep and rest are assumed to be equivalent to the typical European urban background values (Putaud et al., 2010) of 20 μg/m^3. As stated by Zuurbier et al. (2010), the concentrations during driving are assumed to be 1.5 or 2 times the background concentration of $PM_{2.5}$. For this, the average of 1.75 will be used, resulting in an exposure to 35 μg/m^3 $PM_{2.5}$ while traveling with the car. From this reference point, the ratios exposure to air pollution of car/cycle, car/pedestrian and car/public transport need to be used to estimate the concentration of $PM_{2.5}$ cyclists, pedestrians and people traveling with public transport are exposed to.

As earlier mentioned, the ratios exposure to air pollution of car/cycle, car/pedestrian and car/public transport are retrieved from de Hartog et al. (2010) and Cepeda et al. (2017). For the car/cycle ratio, the ratios presented in the two papers are combined resulting in a car/cycle ratio of 1.12 and 31.25 μg/m^3 $PM_{2.5}$ while cycling. The car/public transport ratio used in this research comes from Cepeda et al. (2017) and is established to be 1.3, resulting in an exposure to 26.92 μg/m^3 $PM_{2.5}$ while traveling with public transport. Lastly, the car/walking ratio used in this research also comes from Cepeda et al. (2017) and is established to be 1.16, resulting in an exposure to 30.17 μg/m^3 $PM_{2.5}$ while walking.

Once the total inhaled dose $PM_{2.5}$ per day is estimated using the above numbers and formula (3), this will be used to calculate the ratio of total dose bicycle/car or/and public transport/car. Hereafter, this ratio and the mean $PM_{2.5}$ concentration of car drivers over a 24 hour period in the baseline situation will be used to calculate the equivalent change in $PM_{2.5}$ exposure using the following equation:

$$Equivalent\ change\ in\ PM_{2.5}\ (\mu g/m^3) = (Ratio\ bicycle/car\ - 1) * mean\ PM_{2.5} \tag{4}$$

The last step in estimating the relative risk of changing transport mode related on mortality rate and exposure to air pollution is actually calculating the relative risk. For this calculation, the equivalent change in $PM_{2.5}$ and the average relative risk of all-cause mortality for a change in $PM_{2.5}$ concentration are needed. According to Pope et al. (2002), the average adjusted relative risk of all-cause mortality is 1.06 for a change of 10 $\mu g/m^3$ change in exposure to $PM_{2.5}$ concentration. Using this information, the relative risk related to mortality can be calculated using the following formula:

$$RR\ Mortality = \ e^{\ln(1.06)*(Equivalent\ PM_{2.5}\ change/10)} \tag{5}$$

3.2.2.4. Physical activity

An increase in bicycle transport and public transport increases the average daily physical activity of Rotterdam citizens. For this part of the analysis, the potential impact of physical activity on all-cause mortality from different academic articles will be used and compared in order to establish a relative risk of mortality for commuting with bike compared to non-bike and walking compared to non-walking.

Andersen et al. (2002) studied the relationship between all-cause mortality and different levels of activity. One of their results stated that cycling to work decreased risk of mortality in approximately 40%. The cycling to work was assumed to be 3 hours per week on average, which is close to 7.5 km / 30 min a day which is researched in this study. The relative risk they had found was between 0.55-0.72. Additionally, Matthews et al. (2007) investigated the effects of exercise, walking and cycling for transportation on mortality in the Shanghai Women's Health Study. They found that exercise and cycling for transportation was inversely and independently associated with all-cause mortality. For cycling, they formulated a relative risk range of 0.66-0.79. Furthermore, Hu et al. (2003) did research on whether leisure-time physical activity would be able to reduce the risk of Type 2 diabetes. They found that moderate and high occupational commuting by walking and cycling to work significantly reduces risk of Type 2 diabetes. The relative risk they formulated was in a range of 0.71-0.79.

This results in a relative risk range of 0.55-0.79. For the estimation of relative risk for an increase in physical activity by cycling, the average of 0.67 will be used.

In addition to the relative risk range for cycling, Matthews et al. (2007) and Hu et al. (2003) also formulated relative risk ranges for walking. By Matthews et al. (2007), a reduced risk range for all-cause mortality of 0.65 was found (0.45-0.92). However, while isolating the influences of walking and cycling for transportation, controlling for other types of physical activity, the independent effect of walking for transportation was only weakly associated with all-cause mortality (p = 0.07). Since this is still significant at the 90% significance level, this will still be used in order to estimate the relative risk for walking. Furthermore, Hu et al. (2003) confirmed that walking to and from work is significantly and inversely associated with relative risk of Type 2 diabetes for both sexes. They estimated that the adjusted relative risk with 1-29 minutes of walking is between a range of 0.75-0.96.

This results in a relative risk range of 0.65-0.96. For the estimation of relative risk for an increase in physical activity by walking, the average of 0.81 will be used. Since physical activity while sitting in public transport is the same as while sitting in the car, relative risk of 1 will be used for this. Taking the time-weighted average of these relative risks, the final relative risk of traveling with public transport compared to traveling with car is 0.94.

3.2.2.5. Fatal traffic accidents

The increase in bike transport and walking increases the risk of fatal traffic accidents which should be considered while estimating the effect of the mobility transition on mortality rate. In order to find the relative risk for this stressor, several steps need to be followed. First, the expected traffic deaths per year following the new distribution of road users after the mobility transition will be calculated. Hereafter, this will be used, together with the relative risk of all-cause mortality, in order to establish the relative risk related to fatal traffic accidents.

In order to find the new expected traffic deaths with the new distribution of road users, the number of fatal traffic accidents per billion kilometers travelled will be estimated for the different transport modes for different age groups for each scenario. For each scenario, the total number of kilometers commuted per year will be calculated. To give an example, in scenario 1, 17,000 car trips per day are replaced by 17,000 bicycle trips per day. This indicates that over the whole year, a total of 0.465375 billion kilometers ($17{,}000 * 365 * 7.5 = 46{,}537{,}500$) of car trips are replaced by bicycle trips. Table A5 in the Appendix gives an overview of the billion kilometers replaced in each scenario. To get a more accurate analysis, the number of car trips will be divided by age category since it is expected that more teenagers will transport themselves with bicycles and therefore the impact on mortality rate for each age category will be different. For this, the percentages on traffic participation per mode of transport for each age category using the database *Personenmobiliteit; persoonskenmerken en vervoerwijzen, regio, 2010-2017* from CBS are used (CBS, 2018), shown in Table A6 in the Appendix.

Hereafter, the number of traffic deaths per age category per billion passenger kilometers by bicycle, car, public transport and walking are needed, which are shown in Table A7 in the Appendix. This data has been retrieved from CBS (2020). According to SWOV (2011), within the users of public transport (bus, tram, metro, and train), on average between 2000 and 2009, there was only one death per year. Therefore, this research will assume zero deaths per age category per billion kilometers for public transport. With these numbers, the deaths per year for car travel, bicycle travel and public transport travel will be approximated using the following formula:

$$\begin{aligned} & Expected\ deaths\ per\ year_{{age\ category}_{mode\ of\ transport}} \\ & = kilometers\ per\ year_{{age\ category}_{mode\ of\ transport}} \\ & *\ traffic\ deaths\ per\ billion\ passenger\ kilometers_{{age\ category}_{mode\ of\ transport}} \end{aligned} \tag{6}$$

The last step in this analysis is estimating the relative risk of all-cause mortality that is associated with the shift of transport mode for each scenario using the following formula:

$$\begin{aligned} & Relative\ Risk_{road\ traffic\ accidents} \\ & = \frac{All\ cause\ MR_{age\ category} + \left(MR_{{age\ category}_{bicycle\ /\ PT}} - MR_{{age\ category}_{car}}\right)}{All\ cause\ MR_{age\ category}} \end{aligned} \tag{7}$$

4. Results

This section will elaborate more on the results generated following the methodology that is described above. First, the calculations done for the three different stressors will be presented. If the methodology section was not able to quantify the relative risk for a particular stressor, the calculations needed for this relative risk and final relative risk will be given. Hereafter, for each stressor, the number of deaths prevented in each scenario will be presented. Finally, these will be put together to generate an overview of the final results with total number of deaths prevented, number of life years gained or lost and health costs saved.

4.1. Exposure to air pollution

As described in the methodology section, there are calculations needed to retrieve the relative risk for each scenario for the increase in exposure to air pollution before being able to quantify the effect of the change in air pollution on mortality rate. This will be done using the formulas and indicators selected for minute ventilation and concentration of $PM_{2.5}$ presented in section 3.2.2.3. The overview of calculations, formulas and results for scenario 1, 2 and 3-5 are presented in Tables A8, A9 and A10 respectively. Scenarios 3-5 generate the same relative risk as they all represent a replacement of 50% public transport and 50% bicycle and are therefore put together in one table.

This resulted in the relative risk of replacing car trips by sustainable transport modes on mortality due to an increase in exposure to air pollution of 1.0224 for the first scenario, 1.0034 for the second scenario and 1.0151 for scenarios 3-5. These relative risks are hereafter used to increase the hazard rate in standard life table calculations in order to calculate the change in mortality rate due to an increase in exposure to air pollution. Table 2 represents the yearly results of these standard life table calculations for each scenario.

Table 2. Change in number of deaths per age category per year due to the increase in exposure to air pollution, calculated using standard life table calculations[1] [2]

Age category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
18 – 25	1	1	2	2	1
25 – 35	2	2	7	5	3
35 – 50	22	4	19	14	8
50 – 65	22	4	18	12	7
65 – 75	11	2	8	6	3
75 >	5	1	4	3	1
Total	*62*	*14*	*59*	*41*	*25*

As Table 2 shows, in scenario 1, where 17,000 car trips daily are completely replaced by bicycle trips, this would result in 62 extra deaths yearly due to an increase in exposure to air pollution, on top of the 6,152 deaths in the original situation. These 62 extra deaths are related to the current population, not considering the newborns each year, and with an average life expectancy of 82 years. In scenario 2, when car trips are 100% replaced by public transport trips, this would result in 14 extra deaths per year due to the increase in exposure to air pollution. Lastly, when the car trips are 50% replaced by bicycle trips and 50% by public transport trips, this would result in an increase of 59 deaths with a replacement of 17,000 trips, 41 deaths with a replacement of 12,000 trips and 25 deaths with a replacement of 7,000 trips, due to an increase in exposure to air pollution.

4.2. Physical activity

The relative risks related to the increase in physical activity on mortality rate are presented in section 3.2.2.4. The relative risks of replacing car trips by cycling (scenario 1) and public transport (scenario 2) on mortality are estimated at 0.67 and 0.94, respectively. The relative risk of replacing car trips by both cycling and public transport (scenario 3-5) is estimated to be the average: 0.80. These scenarios generate the same relative risk as they all represent a replacement of 50% public transport and 50% bicycle. As for the analysis of air pollution on mortality, these relative risks are used in standard life table

[1] These numbers have been established using standard life table calculations. For each scenario, the hazard rate was adjusted using the relative risk for air pollution established during the analysis. Hereafter, the calculation is done for 17,000 citizens in the first three scenarios and 12,000 and 7,000 citizens in the fourth and fifth scenario, respectively.

[2] All numbers are rounded

calculations in order to calculate the change in mortality rate due to an increase in physical activity. Table 3 presents the results of these calculations for each scenario for the stressor physical activity.

Table 3. Change in number of deaths per year per age category due to the increase in physical activity, calculated using standard life table calculations [1] [2]

Age category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
18 – 25	- 53	- 10	- 32	- 22	- 13
25 – 35	- 165	- 30	- 97	- 68	- 40
35 – 50	- 497	- 83	- 277	- 196	- 114
50 – 65	- 462	- 76	- 256	- 181	- 106
65 – 75	- 211	- 35	- 118	- 83	- 49
75 >	- 83	- 15	- 48	- 34	- 20
Total	*- 1,471*	*- 249*	*- 828*	*- 586*	*- 341*

These results can be interpreted similarly as the stressor air pollution. As Table 3 shows, in scenario 1, where 17,000 car trips per day are completely replaced by bicycle trips, this would result in 1,471 deaths saved per year due to an increase in physical activity, leading to only 4,636 deaths expected per year in scenario 1. Furthermore, in scenario 2, where 12,000 car trips per day are completely replaced by public transport trips, this would result in 249 deaths per year saved due to an increase in physical activity by walking 10 minutes to and from public transport stations. Lastly, when car trips are 50% replaced by bicycle trips and 50% by public transport trips, this would result in a decrease of 828 deaths per year with a replacement of 17,000 trips per day, 586 deaths per year with a replacement of 12,000 trips per day and 341 deaths per year with a replacement of 7,000 trips per day, due to an increase in physical activity by both walking and cycling.

4.3. Fatal traffic accidents

Before quantifying the effect of the change in fatal traffic accidents on mortality rate, the relative risk for each scenario needs to be calculated. Using the formulas presented in section 3.2.2.5., the relative risk related to fatal traffic accidents can be calculated and the final relative risks for each age group and each scenario are shown in the Appendix, Table A11. The relative risks range from 1 for several age categories and scenarios, to 1.0160 in the category 18-25 in scenario 1. These small relative risks resulted in a change in number of deaths due to the increase in fatal road traffic accidents of zero deaths.

4.4. Final results

All previous steps taken and numbers generated will eventually lead to total change in number of deaths and a gain in life years for the citizens of Rotterdam and the change in health costs for the city of Rotterdam. With these numbers, the research question can be answered.

4.4.1. Mortality rate

As mentioned in section 3.2.2.1., the change in number of deaths and gain in life years per person due to the mobility transition is an indication of the change in mortality rate. For each scenario, the number of deaths saved for each stressor are added up to get the final number of deaths saved. This is shown in Table 4. Tables 5-7 show the total gain in life years saved per person and yearly deaths saved for each stressor and age category in for scenario 1, 2 and 3 respectively. The overview of these results for scenarios 4 and 5 are shown in the Appendix, Tables A12 and A13 respectively. The gain in life years per person gives an indication of the effect of the sustainable mobility transition on the individual level if someone were to adapt this. The yearly deaths saved indicates the change in mortality rate on municipality level. Since the results were small, this is converted to a gain in life days or months. Regarding the gain in life years, the average is taken to find one number for each scenario since gain in life years is on an individual level.

Table 4. Gain in life days/months per person per age category for each scenario

Age category	Scenario 1	Scenario 2	Scenarios 3	Scenario 4	Scenario 5
18 – 25	10 days	2 days	6 days	6 days	6 days
25 – 35	21 days	4 days	11 days	12 days	12 days
35 – 50	1 month and 20 days	9 days	28 days	29 days	29 days
50 – 65	1 month and 22 days	9 days	29 days	29 days	29 days
65 – 75	1 month and 21 days	9 days	29 days	29 days	29 days
75 >	26 days	5 days	15 days	15 days	15 days
Average	*1 month and 5 days*	*6 days*	*20 days*	*20 days*	*20 days*

As Table 4 shows, every traveler within Rotterdam that changes 100% of their car trips to cycling for one year, would on average gain one month and five days of their lives. Moreover, every traveler within Rotterdam that changes 100% of their car trips to public transport trips for one year, would on average gain six days of their lives. Lastly, every traveler within Rotterdam that changes 50% of its car driving trips to bicycle trips and the other 50% of its car driving trips to public transport trips for one year, would gain 20 days of their lives on average.

Table 5. **Scenario 1: Final results of number of deaths saved and life days/months gained or lost from replacing 17,000 car trips by bicycle trips (100%) per day for trips of 7.5 km / 30 min per age group**

Stressor	Age category	Baseline mortality rate [3]	Relative Risk [4]	Number of deaths saved [5]	Gain in life days/months per person [6]
Air pollution	18 – 25	167	1.0224	- 1	- 0.1 days
	25 – 35	538	1.0224	- 2	- 0.3 days
	35 – 50	2,139	1.0224	- 22	- 2.4 days
	50 – 65	2,025	1.0224	- 22	- 2.6 days
	65 – 75	870	1.0224	- 11	- 2.9 days
	75 >	276	1.0224	- 5	- 1.8 days
Physical activity	18 – 25	167	0.6700	53	10.5 days
	25 – 35	538	0.6700	165	20.9 days
	35 – 50	2,139	0.6700	497	1 month and 24.1 days
	50 – 65	2,025	0.6700	462	1 month and 26.2 days
	65 – 75	870	0.6700	211	1 month and 25.6 days
	75 >	276	0.6700	83	28 days
Fatal traffic accidents	18 – 25	167	1.0160	0	0 days
	25 – 35	538	1.0055	0	0 days
	35 – 50	2,139	1.0014	0	0 days
	50 – 65	2,025	1.0003	0	0 days
	65 – 75	870	1.0001	0	0 days
	75 >	276	1.0000	0	0 days
Total				***1,408***	***1 month and 5.5 days (average)[7]***

[3] Applied to 17,000 individuals with different age categories
[4] Relative risks for air pollution, physical activity and fatal traffic accidents are retrieved from Table A8, Section 3.2.2.4. and Table A10 respectively
[5] Number of deaths saved in the municipality Rotterdam if 17,000 people were to adapt the mobility transition every day for a year
[6] Gain in life days/months per person who adapted the mobility transition every day for a whole year
[7] The average is taken since these results are per person

Table 6. Scenario 2: Final results of number of deaths saved and life days/months gained or lost from replacing 17,000 car trips by public transport trips (100%) per day for trips of 7.5 km / 30 min per age group

Stressor	Age category	Baseline mortality rate [3]	Mean Relative Risk [4]	Number of deaths saved [5]	Gain in life days/months per person [6]
Air pollution	18 – 25	167	1.0034	- 1	- 0.1 days
	25 – 35	538	1.0034	- 2	- 0.2 days
	35 – 50	2,139	1.0034	- 4	- 0.5 days
	50 – 65	2,025	1.0034	- 4	- 0.5 days
	65 – 75	870	1.0034	- 2	- 0.5 days
	75 >	276	1.0034	- 1	- 0.3 days
Physical activity	18 – 25	167	0.9400	10	2.0 days
	25 – 35	538	0.9400	30	3.9 days
	35 – 50	2,139	0.9400	83	9.0 days
	50 – 65	2,025	0.9400	76	9.3 days
	65 – 75	870	0.9400	35	9.4 days
	75 >	276	0.9400	15	5.1 days
Fatal traffic accidents	18 – 25	167	1.0014	0	0 days
	25 – 35	538	1.0005	0	0 days
	35 – 50	2,139	1.0001	0	0 days
	50 – 65	2,025	1.0000	0	0 days
	65 – 75	870	1.0000	0	0 days
	75 >	276	1.0000	0	0 days
Total				***237***	***6.1 days (on average)*** [7]

Table 7. Scenario 3: Final results of number of deaths saved and life days/months gained or lost from replacing 17,000 car trips by bicycle (50%) and public transport (50%) trips per day for a year, for trips of 7.5 km / 30 min per age group

Stressor	Age category	Baseline mortality rate [3]	Mean Relative Risk [4]	Number of deaths saved [5]	Gain in life days/months per person [6]
Air pollution	18 – 25	112	1.0151	- 2	- 1 day
	25 – 35	573	1.0151	- 7	- 1 day
	35 – 50	1,942	1.0151	- 19	- 2 days
	50 – 65	15,842	1.0151	- 18	- 2 days
	65 – 75	28	1.0151	- 8	- 2 days
	75 >	28	1.0151	- 4	- 1 day
Physical activity	18 – 25	1,942	0.8000	32	6 days
	25 – 35	15,842	0.8000	97	12 days
	35 – 50	28	0.8000	277	30 days
	50 – 65	28	0.8000	256	31 days
	65 – 75	112	0.8000	118	31 days
	75 >	573	0.8000	48	16 days
Fatal traffic accidents	18 – 25	28	1.0087	0	0 days
	25 – 35	28	1.0030	0	0 days
	35 – 50	112	1.0008	0	0 days
	50 – 65	573	1.0002	0	0 days
	65 – 75	1,942	1.0001	0	0 days
	75 >	15,842	1.0000	0	0 days
Total				***770***	***20 days (on average)*** [7]

4.4.2. Health costs

The last part of the analysis involves estimating the financial impact of the change of mode of transport for each scenario. As mentioned before, this will be done using Value of Statistical Life. According to the HEAT tool, all-cause mortality can be monetized by using the VSL of 3,900,000 euros per death (WHO, 2019). Since the expected age in Rotterdam is 82 (Hindremäe, 2020), the VSL per year can be estimated at 47,561 euros per death per year. Using this information, the expected savings in health costs per year can be estimated. Results per scenario are shown in Table 8.

Table 8. Estimated number of deaths prevented per year and savings in health costs related to the mobility transition of 17,000 will (scenario 1-3), 12,000 (scenario 4), and 7,000 (scenario 5) trips of 7.5 km / 30 min

	# deaths prevented per year	Savings in health costs per year
Scenario 1	1408	€ 66,965,854
Scenario 2	237	€ 11,271,951
Scenario 3	770	€ 36,621,951
Scenario 4	543	€ 25,825,610
Scenario 5	317	€ 15,076,829

As the Table 8 shows, in scenario 1, in which 17,000 car trips are 100% replaced by bicycle trips, 770 deaths will be saved, resulting in health cost savings of 66,965,854 euros per year. In scenario 2, in which 17,000 car trips are 100% replaced by public transport trips, 237 deaths will be saved, resulting in health cost savings of 11,271,951 euros per year. Additionally, in scenario 3, in which 17,000 car trips are replaced by 50% bicycle trips and 50% public transport trips, 770 deaths will be saved, resulting in health cost savings of 36,621,951 euros per year. Furthermore, if the formulated goal of reducing 17,000 car trips does not succeed completely, and only 12,000 car trips are reduced (scenario 4), 543 deaths will be saved, and this will result in 25,825,610 euros saved in health costs per year. Lastly, if only 7,000 car trips are reduced (scenario 5), this will result in a gain of 317 deaths saved, and savings in health costs to the amount of 15,076,829 euros per year.

5. Discussion & conclusion

5.1. Discussion

5.1.1. Findings

This research quantified the health benefits from a transport transition of car driving to cycling and taking public transport for short trips (7.5 km / 30 min) by comparing the difference in exposure to air pollution, physical activity and fatal traffic accidents in Rotterdam. These comparisons have been performed by identifying the relative risks and relating these to mortality rate for each stressor and mode of transport. The relative risk related to air pollution and traffic accidents is higher for individuals traveling with bicycle and public transport than for individuals traveling with car. On the other hand, the relative risk related to physical activity is lower for people traveling with bicycle and public transport than for people traveling by car. This resulted in a number of life years saved ranging from a loss of three days due to an increase in exposure to air pollution to a gain of one month and 26 days due to the increase in physical activity, with potential savings that range from € 11,271,951 to € 66,965,854 in health costs.

Looking at the results, it is safe to say that a transition from car driving to traveling with bicycle and public transport could potentially improve the health of the population of Rotterdam, given that in all scenarios at least 237 deaths would be saved. The largest benefit would be due to an increase in physical activity of the travelers. Its impact on mortality is approximated to be 21 times higher than the impact on mortality rate due to the increase in exposure to air pollution. This is not a surprising finding since past research done on this has found similar results. De Hartog et al. (2010) had found that the increase in physical activity would lead to a 9 times more gains in life years than the losses in life years due to traffic accidents and exposure to air pollution. Moreover, Lindsay et al. (2011) found that the health benefits from physical activity for a shift of 5% of the passenger kilometers to cycling would lead to 116 deaths avoided annually. The number of deaths saved due to the increase in physical activity results in a number of at least 249 in scenario 2. This confirms the hypothesis formulated in section 2.1.2. which states that the increase in physical activity due to the change from car trips to bicycle and public transport trips will lead to a lower mortality rate for the citizens of Rotterdam.

It is also interesting to note that the change in mortality rate due to fatal traffic accidents is practically zero. This result does not confirm the hypothesis formulated in section 2.2.3. which states that the increase in fatal traffic accidents due to the change from car trips to bicycle and public transport trips will lead to a lower mortality rate for the citizens of Rotterdam. This result is likely to be explained by the fact that yearly numbers of yearly fatal traffic accidents among cyclists and car drivers are very similar. As earlier mentioned, there were only 661 fatal traffic accidents in 2019 according to SWOV (2020). One third of which being car drivers (237) and a little less than one third being cyclists (203). These numbers, relatively, do not differ by that many. Furthermore, since number of fatal traffic accidents per billion passenger kilometers is taken, this is substantially small. For the estimation of the change in traffic accidents, it would have probably led to higher results if traffic injuries were also considered. Similar studies done on this subject have found a substantial impact of fatal traffic accidents. De Hartog et al. (2010) found that the increase in traffic accidents due to a change in transport mode would cause an average loss in life days of seven per person, applied to 500,000 subjects between ages 18-64.

Moreover, discussing the results of the increase in air pollution on mortality rate, the hypothesis identified in section 2.2.1. which states that the increase in exposure to air pollution due to the change from car trips to bicycle and public transport trips will lead to a higher mortality rate for the citizens of Rotterdam is confirmed. In all scenarios the increase in exposure to air pollution leads to an increase in number of deaths per year, ranging from 14 in scenario 2 in which 100% of the car trips is replaced by public transport trips to 62 in scenario 1 in which 100% of the car trips are replaced by bicycle trips. Since there is a lot more exposure to $PM_{2.5}$ while traveling with the bicycle this is a logical end result.

Looking at the overall results, scenario 1 (100% change from car trips to bicycle trips) would be the most favorable since in this scenario most deaths are prevented. This is due to the fact that physical activity has the largest impact on mortality rate, and in scenario 1, the increase in physical activity is largest. Even though scenario 1 is most favorable, it is most likely to assume that scenario 3, 4 or 5 is more likely to happen. Especially in the Netherlands, weather is unpredictable. In bad weather, people are more likely to take public transport instead of cycling or stick to their old habits and taking the car. Additionally, public transport is often the easier option. Therefore, either scenario 3, 4 or 5 is more likely to happen. This would however result in a lesser impact on mortality rate. With these insights and considering the *Rotterdamse Mobiliteits Aanpak*, it is recommended to focus mostly on stimulating the change to bicycle transport.

Furthermore, it is interesting to note that the age categories 35-50, 50-65, and 65-75 would have the highest benefit from the mobility transition. Looking at Table 4 and considering the yearly gain in life days, it can be concluded that, on average, the impact on mortality rate for these three age categories is three times higher than the impact on mortality rate for the other age categories. This is likely to be the case due to the fact that these age categories are most likely to travel with car in general. According to CBS (2020), 86% of the cars are owned by these three age categories. It is therefore most likely that the people between 35 and 75 will have the highest benefits from the mobility transition.

5.1.2. Strengths and weaknesses

Considering the methodology of this research, there are several limitations. Firstly, the stressors that are chosen to estimate the change in mortality rate are limited. Only three stressors out of many other factors that come with this policy are estimated. As previous research has shown, the increase in exposure to air pollution, physical activity, and fatal traffic accidents do have a large effect on mortality rate due to this transport mode transition (Litman et al., 2009; De Hartog et al., 2010; Lindsay et al., 2011; Rojas-Rueda et al., 2012). However, as also mentioned by Joffe and Mindell (2002), there are several other factors that could possibly lead to a change in mortality rate. Several factors that they mention are the decrease in emission of pollutants which could lead to a lesser increase in exposure estimated in this research. Furthermore, not only fatal traffic accidents would be likely to increase, also (severe) injuries. Lastly, there could be an increase in social use of outdoor spaces, less noise disturbance, and less stress. These other factors are not considered in this research but are likely to have an effect on mortality rate. The change in mortality rate estimated in this research is therefore likely to be underestimated.

Elaborating more on the limitations around the estimation of the effect of an increase in mortality rate due to an increase in exposure to air pollution, there are several discussion points. Firstly, as earlier mentioned, a decrease of car usage would also lead to a decrease in overall air pollution. This would not only be beneficial for the 17,000 people measured in this research, but also for the other inhabitants of Rotterdam. The number of deaths mentioned in this research is therefore underestimated. This is also confirmed by De Hartog et al. (2010) who estimated that for approximately 800,000-160,000 inhabitants of major streets in the Netherlands, mortality rates could be 1.012 times lower. Secondly, this research only estimates the effect of an increase in exposure to the air pollutant $PM_{2.5}$. However, there are more types of air pollutants that have an effect on health and mortality rate. Rojas-Rueda et al. (2012), for example, also estimate the effect of PM_{10}, and De Hartog et al. (2010) also estimate the effect of black smoke (BS). Additionally, Beelen et al. (2008) found a significant association between natural-cause and respiratory mortality for NO_2 and BS. Lastly, this research has used data on $PM_{2.5}$ of other works. However, there is Rotterdam-specific data on this provided by DCMR. This has not been used since the actual data needed is quite complicated to retrieve. For future research, this would generate more accurate results.

An additional limitation to this research is that it works with many assumptions and averages. First of all, the assumptions made while estimating the inhaled dose of air pollution per day per activity. This estimation starts with the ratios of minute ventilation for different activities. This highly affects the estimated inhaled dose per day per activity for the population. This research has used the assumption that the ratios of minute ventilation for [Bike, walk, car, public transport, rest, sleep] is equal to [6, 4, 1, 1, 1, 0.5] (Johnson, 2002; de Nazelle et al., 2009; de Hartog et al., 2010). However, other research done on minute ventilations for different activities have found different ratios. For example, according to van Wijnen et al. (1995), the minute ventilation of a cyclist is 2.3 times higher than that of a car driver and Zuurbier et al. (2009) found that this number was 2.1. Zuurbier et al. (2009) also found that the average minute ventilation while traveling with public transport is 2.0 times higher than while driving a car. These ratios are not used in this research since they do not include a ratio for walking. However, it should still be noted that if these minute ventilations were assumed in this research, this would have led to a smaller change in mortality rate due to air pollution.

Another assumption used in de calculation of inhaled dose of air pollution per activity was the assumption that concentrations of $PM_{2.5}$ during sleep and rest were assumed to be equivalent to typical European urban background values (de Hartog et al., 2010; Putaud et al., 2010). From this starting point, using the ratios found by previous research, the concentration of $PM_{2.5}$ the population is exposed to is calculated. These assumptions are accurate since they are scientifically proven, however, the concentration of $PM_{2.5}$ someone is exposed to depends largely on the day, week, location of street in Rotterdam, whether the bicycle lane is right next to the car lane and lots of other factors. Therefore, these are accurate assumptions, but they could be closer to the truth by estimating an average for each period of the year.

Moreover, this research has only considered the effect of the mobility transition for the age categories above 18 years old. This decision makes the estimation a lot more accurate since age categories for which the mobility transition is not possible are not considered. Children below the 18 years old are not allowed to drive a car by themselves yet. Therefore, they are not able to make the transportation mode transition. Furthermore, those children are likely to not be comfortable to take public transport. However, if further research were to include the decrease of overall level of air pollution, it would be interesting to also consider the effect of the mobility transition on children. Moreover, this research does take the population above 75 years old into account since they are able to make the mobility transition. It is, however, unlikely that every person above the 75 years old is physically able to transport themselves with the bicycle or public transport. Additionally, Vogel et al. (2009) proved that the relative risks of physical activity are larger for elderly. With this information, it might be interesting for future research to take this into account while assessing the relative risk of physical activity for different age categories.

Looking at the extent to which this research captures the relationship between a mobility shift and health benefits for the city of Rotterdam, the methodology has tried to isolate just this cause and effect in several ways. For the increase in exposure to air pollution, this study only estimated the change in air pollution for a change of mode of transport for half an hour per day. The other activities during the day are assumed to stay the same as they were all assumed to be in rest. Moreover, for the relative risk estimation of physical activity, the articles used really captured the relative risk related to a mobility shift for short trips and as transportation mode. In contrast to these measures, there are several stressors not considered in this research (e.g. noise disturbance, stress levels). Furthermore, there is a new trend up and coming that is also not considered in this research. With the new technologies, Rotterdam is one of the many cities that has adapted e-bikes, share-scooters and several of these new mobility trends. This new mobility trend would affect the outcome in two ways: it would decrease the level of physical activity and it would increase the level of road accidents. Namely, according to Solanki (2017), the percentage of road causalities that involve e-bikes has gone up and will keep increasing. For these several reasons, the total effect of the mobility transition is not captured in this research, but only part of it.

Lastly, looking at the extent to which this outcome would be expected to apply in other settings, this might not entirely be the case. As this research shows, the health benefits are mostly due to the change in physical activity. Since this is the same for every city, this part of the results would not differ and there would be a large health benefit for each city that would apply the mobility transition. In contrast, this research has been performed for Rotterdam, a large city in the Netherlands. The Netherlands is provided with a lot of safe and good bicycle lanes and the city of Rotterdam has a very well organized public transport infrastructure. If such a research were to be executed in a different country, for example Spain or France, where cyclists are not provided with safe bicycle paths, the mobility transition would be a lot more difficult. The results could differ due the fact that the risk of a fatal accident is a lot higher.

5.1.3. Recommendations

5.1.3.1. Future research

Based on the discussion points mentioned above, there are several suggestions for future research. The most important suggestion would be to estimate more factors than the three estimated in this research (exposure to air pollution, physical activity and fatal traffic accidents). Other factors that could be considered are the decrease in noise disturbance and stress level. A decrease in noise disturbance has proved to lead to a better night sleep and therefore better health. This is proven by Öhström and Rylander (1990) who proved that sleep quality decreased with increased number of noise events. Moreover, stress levels are proven to be significantly higher for car commuters compared to train commuters (Wener & Evans, 2011).

Additional to levels of stress and noise disturbance, the biggest additional factor that should be considered is the decrease in overall air pollution. In previous research in the Netherlands, this has been done by following the Calculation of Air pollution from Road traffic (CAR) model (De Hartog et al., 2010). This is a model explained by Eerens et al. in 1993 but there are more recent models found in order to estimate the quality of air. Additionally, Rojas-Rueda et al. (2012) used the Barcelona Air-Dispersion Model (Lao and Teixido, 2011). With this model, specifically made for Barcelona, the change in concentration in each different area in Barcelona (1482 different areas) can be measured, also considering the number of inhabitants and the age distribution of each area. If such a model could be used for the city of Rotterdam, this is a very interesting addition to the research since it would affect the entire population instead of the travelers only. As discussed earlier, this research found that the increase in physical activity had the largest health benefits. The negative health benefits due to the increase in exposure to air pollution was a lot smaller. Therefore, it is expected that the addition of the overall level of air pollution will not effect the change in mortality rate by that much, but it would still be interesting to note by how much the population as a whole would benefit, instead of only the travelers.

Furthermore, considering air pollution, it would be recommended to also estimate the effect of different air pollutants instead of only $PM_{2.5}$. According to WHO (n.d.), the pollutants that have the strongest evidence to have a negative effect on health of individuals are ozone (O_3), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2). Additionally, de Hartog et al. (2010) also used the estimation of the effect of an increase in exposure to black smoke (BS) due to the mobility transition. In order to get a more accurate picture, it would be interesting to also measure the change and effect of these air pollutants.

Moreover, as earlier mentioned, since Vogel et al. (2009) found that relative risks of physical activity are larger among the elderly, future research could not only take this into account, but also different relative risks for the other age groups. It is likely that the relative risk of physical activity is increasing with age, as younger children often move around more during the day and still play sports. This could increase the relative risk and effect of this on mortality rate for the elderly in the population, but also decrease the relative risk and effect of this on mortality rate for the younger people in the population.

Lastly, this research only considers the effect of the stressors on all-cause mortality rate. It could also be interesting to research the effect of the change in these stressors on different diseases which are often caused by the different stressors. For this, cardiovascular diseases could be considered for the stressor air pollution and obesity diseases could be considered for the stressor physical activity. This would give a more complete picture of the effects of the mobility transition.

5.1.3.2. Policies

Looking at the results of this research, it can be recommended for the *RMA* and the city government of Rotterdam to mostly focus on promoting the mobility transition towards cycling and for the age categories 35-75. This can be recommended since the results show that the largest benefit from the mobility transition is due to physical activity while cycling and for the age categories 35-50, 50-65, and 65-75. If the city government were to focus on these two elements, the highest benefits from the *RMA* can be achieved.

5.2. Conclusion

In conclusion, this paper answered the research question: "*To what extend will the replacement of car transport to walking, cycling and public transport have an effect on all-cause mortality and health costs for the citizens of Rotterdam?"*. This question is answered by looking at three different stressors: exposure to air pollution, physical activity and fatal traffic accidents, in five different scenarios based on the *RMA* in which the number of car trips replaced and replacement transport modes differ. By calculating the relative risks of the different transportation modes for each stressor in each situation, the number of deaths saved and life years gained for different age groups can be quantified. This resulted in a number of life years saved ranging from a loss of three days due to an increase in exposure to air pollution to a gain of one month and 26 days due to the increase in physical activity, with potential savings in health costs that range from € 11,271,951 to € 66,965,854. It can be concluded that the mobility shift would have a positive effect on all-cause mortality rate and health costs for the citizens of Rotterdam due to the large impact of the increase in physical activity. This positive effect is reduced by the increase in exposure to air pollution and there is almost no change in fatal traffic accidents. The shift of 17,000 car trips formulated by the *Rotterdamse Mobiliteits Aanpak* would be positive for the travelers making this shift and the health costs of Rotterdam and could potentially change the lives of many individuals.

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Appendix

Table A1. **Overview findings from research de Hartog et al. (2010) on air pollution exposure during car driving and cycling**

Research	Mean concentration $PM_{2.5}$ car ($\mu g/m^3$)	Mean concentration $PM_{2.5}$ cycling ($\mu g/m^3$)	Ratio car/cycle
Adams et al. (2001)	37	28	1.32
Kaur et al. (2005)	38	34	1.12
Boogaard et al. (2009)	49	45	1.11
Zuurbier et al. (2010)	78	72	1.09
Mean of ratios			*1.16*

Table A2. **Overview findings from research done by Cepeda et al. (2017) on comparison of ratio of exposure to air pollution ($PM_{2.5}$) according to mode of transport to that of cyclists**

Ratio	Median	95% Confidence Interval
Cyclists / cyclists over high traffic route	1.01	(0.53, 1.91)
Cyclists / bus	1.05	(0.94, 1.19)
Cyclists / car	1.05	(0.89, 1.25)
Cyclists / car with controlled ventilation settings	0.95	(0.84, 1.07)
Cyclists / MMT	0.73	(0.46, 1.14)
Cyclists / motorcycle	0.84	(0.79, 0.90)
Cyclists / pedestrians	0.82	(0.71, 0.94)

Adapted source: Centraal Bureau voor de Statistiek (2020)

Table A3. **Distribution of age groups used for the estimation of effect on mortality rate (in percentages)**

Age category	Percentage of total
< 12	13
12 – 18	7
18 – 25	11
25 - 35	17
35 - 50	20
50 - 65	18
65 - 75	8
75 >	6

Adapted source: Centraal Bureau voor de Statstiek (2020)

Table A4. **Baseline number of deaths in Rotterdam, calculated using standard life table calculations**

Age category	Scenario 1 – 3	Scenario 4	Scenario 5
18 – 25	167	118	69
25 – 35	538	379	221
35 – 50	2,139	1,510	881
50 – 65	2,025	1,429	834
65 – 75	870	614	358
75 >	276	195	114
Total	*6,152*	*4,343*	*2,533*

Table A5. Total number of car trip kilometers replaced by bicycle or public transport kilometers per year for each scenario

Scenario	Reduced car trips (billion km)	Replaced by bicycle trips (billion km)	Replaced by PT (billion km)
1	0.04653750	0.04653750	0
2	0.04653750	0	0.04653750
3	0.04653750	0.02326875	0.02326875
4	0.03285000	0.01642500	0.01642500
5	0.01916250	0.00958125	0.00958125

Table A6. Road participants per transport mode in 2017 in percentages

Age category	Car	Bicycle	Public Transport
18 – 25	10.1	15.2	35.4
25 – 35	16.5	9.4	14.9
35 – 50	18.4	12.2	8.5
50 – 65	14.8	12.3	12.2
65 – 75	12.3	9.9	9.2
75 >	9.4	4.6	0

Adapted source: Centraal Bureau voor de Statistiek (2020)

Table A7. Number of traffic deaths per age category per billion passenger kilometer by bicycle and by car in the Netherlands in 2017[a]

Age category	Car	Bicycle	Public Transport	Walking
18 – 25	0.15	2.6	0	1.46
25 – 35	0.07	2.0	0	1.04
35 – 50	0.03	2.0	0	0.83
50 – 65	0.05	2.5	0	0.83
65 – 75	0.04	2.6	0	1.04
75 >	0.33	1.4	0	4.79

Adapted source: Centraal Bureau voor de Statistiek (2020)

[a] Estimated as traffic mode-specific and age-specific number of traffic deaths divided by the total amount of kilometers driven per age and traffic mode in the year 2017 in the Netherlands

Table A8. Scenario 1: Calculation of relative risk relating to the change in exposure to air pollution of cycling compared to car driving

Activity	Minute ventilation (m^3/h) [9]	Duration (h/day) [10]	Concentration $PM_{2.5}$ (µg/day) [11]	Inhaled dose per activity (µg/day) [12]	Total dose (µg/day) [13]	Ratio of total dose cycle/car [14]	Mean $PM_{2.5}$ concentration (µg/m^3) [15]	Equivalent change in $PM_{2.5}$ (µ/m^3) [16]	RR Mortality [17]
Sleep	0.18	8.00	20.00	28.80					
Rest	0.36	15.50	20.00	111.60					
Car driving	0.36	0.50	35.00	6.30	146.70				
Cycling	2.16	0.50	31.25	33.25	174.15				
Total						*1.187*	*20.313*	*3.801*	*1.0224*

[9] Minute ventilation in rest is assumed to be 6 liters/minute (0.36 m^3/h) (Benumof, 2012). According to De Hartog et al. (2010), the minute ventilation sleep/rest ratio is 1/2, therefore the minute ventilation while sleeping is 3 l/m (0.18 m^3/h). Furthermore, taking the ratios formulated by Rojas-Rueda et al. (2012) this results in the following ratios: [Bike, walk, car, public transport, rest, sleep] = [6, 4, 1, 1, 1, 0.5].

[10] Only the impact of replacing an half hour (7.5 km) trip is considered. Therefore, the rest of the day is assumed to be in rest.

[11] According to de Hartog et al. (2010), the concentrations of $PM_{2.5}$ during sleep and rest are assumed to be equivalent to the typical European urban background values (Putaud et al., 2010) of 20 µg/m^3. According to Zuurbier et al. (2010), the concentrations during driving are assumed to be 1.5 or 2 times the background concentration of $PM_{2.5}$. The average of 1.75 is used. Lastly, the concentration of $PM_{2.5}$ for cyclists, walking and public transport is assumed to be 0.893, 0.862, and 0.769 times the concentration estimated for car drivers, respectively.

[12] Inhaled dose of $PM_{2.5}$ is calculated per activity using the following formula (1)

[13] Total inhaled dose of $PM_{2.5}$ per day is calculated using the following formula: $Total\ inhaled\ dose\ (\mu g/day) = Inhaled\ dose\ during\ sleep + rest + driving/cycling/walking/public\ transport$

[14] The ratio of exposure to total dose of $PM_{2.5}$ for cycle/car is calculated using the following formula: $Ratio\ of\ total\ dose\ cycle\ and\ public\ transport/car = total\ dose\ cycling\ and\ public\ transport\ (\mu g/day)\ /\ total\ dose\ car\ driving\ (\mu g/day)$

[15] The mean concentration of $PM_{2.5}$ someone driving a car is exposed to is calculated by taking the time-weighted average $PM_{2.5}$ exposures over a 24-hour period.

[16] The equivalent change in exposure to concentration of $PM_{2.5}$ is calculated using the following formula: $Equivalent\ change\ in\ PM_{2.5}\ (\mu g/m^3) = (Ratio\ bicycle/car - 1) * mean\ PM_{2.5}$

[17] According to Pope et al. (2002), the average adjusted relative risk of all-cause mortality is 1.06 for a change of 10 µg/m^3 change in exposure to $PM_{2.5}$ concentration. Using this information, the Relative Risk (RR) is estimated using the following formula: $RR\ Mortality = e^{\ln(1.06)*(Equivalent\ PM_{2.5}\ change/10)}$

Table A9. **Scenario 2: Calculation of the potential mortality rate impact related to exposure to air pollution of public transport compared to car driving**

Activity	Minute ventilation (l/h) [9] above	Duration (h/day) [10]	Concentration $PM_{2.5}$ (µg/day) [11]	Inhaled dose per activity (µg/day) [12]	Total dose (µg/day) [13]	Ratio of total dose PT/car [14]	Mean $PM_{2.5}$ concentration (µg/m^3) [15]	Equivalent change in $PM_{2.5}$ (µ/m^3) [16]	RR Mortality (equal toxicity) [17]
Sleep	0.18	8.00	20.00	28.80					
Rest	0.36	15.50	20.00	111.60					
Car driving	0.36	0.50	35.00	6.30	146.70				
Walking	1.44	0.17	30.17	7.26					
Public transport	0.36	0.33	26.92	3.23	150.88				
Total						*1.029*	*20.313*	*0.579*	*1.0034*

Table A10. **Scenarios 3-5: Calculation of Relative Risk relating to the change in exposure to air pollution of cycling and public transport compared to car driving**

Activity	Minute ventilation (l/h) [9]	Duration (h/day) [10]	Concentration $PM_{2.5}$ (µg/day) [11]	Inhaled dose per activity (µg/day) [12]	Total dose (µg/day) [13]	Ratio of total dose cycle/car [14]	Mean $PM_{2.5}$ concentration (µg/m^3) [15]	Equivalent change in $PM_{2.5}$ (µ/m^3) [16]	RR Mortality [17]
Sleep	0.18	8.00	20.00	28.80					
Rest	0.36	15.50	20.00	111.60					
Car driving	0.36	0.50	35.00	6.30	146.70				
Cycling	2.16	0.25	31.25	16.88					
Walking	1.44	0.17	30.17	7.26					
Public transport	0.36	0.08	26.92	0.804	165.34				
Total						*1.127*	*20.313*	*2.580*	*1.0151*

Table A11. Relative risks retrieved from analysis on fatal traffic accidents per scenario per age category

Age category	Scenario 1	Scenario 2	Scenario 3 – 5
18 – 25	1.0160	1.0014	1.0087
25 – 35	1.0055	1.0005	1.0030
35 – 50	1.0014	1.0001	1.0008
50 – 65	1.0003	1.0000	1.0002
65 – 75	1.0001	1.0000	1.0001
75 >	1.0000	1.0000	1.0000

Table A12. Scenario 4: Analysis of life years gained or lost from replacing 12,000 car trips by bicycle (50%) and public transport (50%) trips per day for trips of 7.5 km / 30 min per age group

Stressor	Age category	Baseline mortality rate	Mean Relative Risk	Number of deaths saved	Gain in life days/months per person
Air pollution	18 – 25	118	1.0151	- 2	- 0.5 days
	25 – 35	379	1.0151	- 5	- 0.7 days
	35 – 50	1,510	1.0151	- 14	- 1.5 days
	50 – 65	1,429	1.0151	- 12	- 2.1 days
	65 – 75	614	1.0151	- 6	- 2.2 days
	75 >	195	1.0151	- 3	- 1.2 days
Physical activity	18 – 25	118	0.8000	22	6.2 days
	25 – 35	379	0.8000	68	12.3 days
	35 – 50	1,510	0.8000	196	30.1 days
	50 – 65	1,429	0.8000	181	31.2 days
	65 – 75	614	0.8000	83	31.2 days
	75 >	195	0.8000	34	16.4 days
Fatal traffic accidents	18 – 25	118	1.0087	0	0 days
	25 – 35	379	1.0030	0	0 days
	35 – 50	1,510	1.0008	0	0 days
	50 – 65	1,429	1.0002	0	0 days
	65 – 75	614	1.0001	0	0 days
	75 >	195	1.0000	0	0 days
Total				***543***	***19.9 days (on average)***

Table A13. **Scenario 5: Analysis of life years gained or lost from replacing 7,000 car trips by bicycle (50%) and public transport (50%) trips per day for trips of 7.5 km / 30 min per age group**

Stressor	Age category	Baseline mortality rate	Mean Relative Risk	Number of deaths saved	Gain in life days/months per person
Air pollution	18 – 25	69	1.0151	- 1	- 0.5 days
	25 – 35	221	1.0151	- 3	- 0.5 days
	35 – 50	881	1.0151	- 8	- 1.2 days
	50 – 65	834	1.0151	- 7	- 2.1 days
	65 – 75	358	1.0151	- 3	- 2.2 days
	75 >	114	1.0151	- 1	- 1.2 days
Physical activity	18 – 25	69	0.8000	13	6.2 days
	25 – 35	221	0.8000	40	12.3 days
	35 – 50	881	0.8000	114	30.1 days
	50 – 65	834	0.8000	106	31.2 days
	65 – 75	358	0.8000	49	31.2 days
	75 >	114	0.8000	20	16.4 days
Fatal traffic accidents	18 – 25	69	1.0087	0	0 days
	25 – 35	221	1.0030	0	0 days
	35 – 50	881	1.0008	0	0 days
	50 – 65	834	1.0002	0	0 days
	65 – 75	358	1.0001	0	0 days
	75 >	114	1.0000	0	0 days
Total				***317***	***19.9 days***