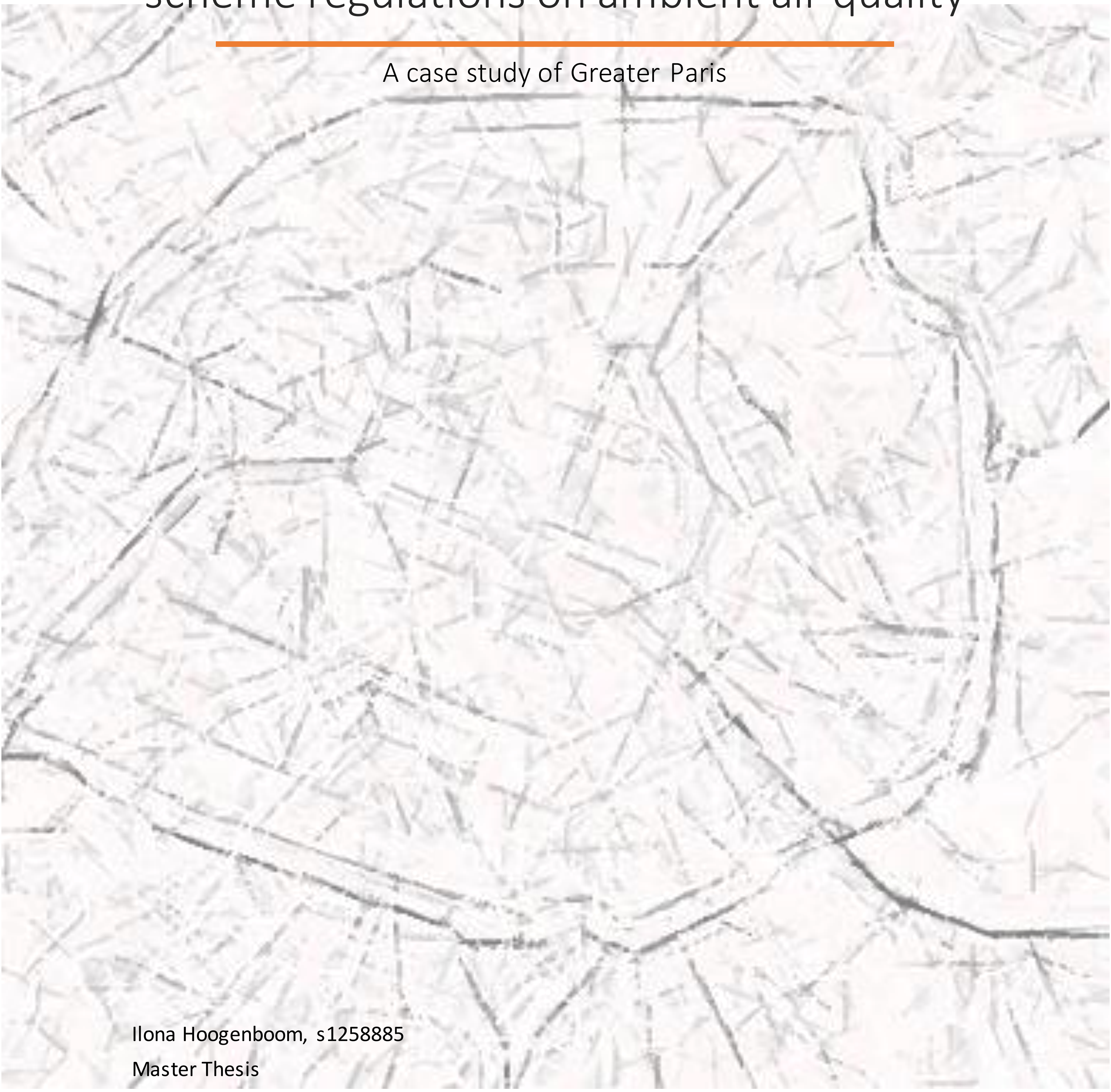
Assessing the effectiveness of smog scheme regulations on ambient air quality

A case study of Greater Paris



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Abstract

Poor air quality increases the risk of health problems such as cancers, cardiovascular- and respiratory diseases. Moreover, exposure to ambient air pollution is one of the major environmental causes of premature death. In order to protect human health and to comply with European legislation, many European cities have introduced low emission zones. The environmental zone in Greater Paris has a novelty: the regulations become effective in case of a peak in pollution. This study investigates the effectiveness of this smog scheme. The effect of activation of the smog scheme regulations on ambient air quality is studied with the use of OLS regressions on hourly data of particulate matter and nitrogen dioxide concentrations. The findings show that the n1 regulations have no effect. The n2 regulations seem to have a negative effect on air pollution. However, the findings are not univocal, which underlines the importance of further research.

Table of contents

List of figures and tables

Figures

Tables

1. Introduction

Research points out that air pollution is one of the major environmental causes of premature death. High levels of pollution are currently estimated to cause over 4 million premature deaths worldwide per year (Cariolet et al., 2018; WHO, 2018). Moreover, poor air quality increases the risk of health problems such as cancers, cardiovascular diseases and respiratory diseases (Airparif, 2018; WHO n.d.). The importance of these health effects is reinforced by studies demonstrating that levels of air pollution will continue to rise in densely populated areas in the coming decades (OECD, 2012).

In order to address these issues, the European Commission adopted in 2008 a directive on ambient air quality, aimed at the protection of the environment and human health (Directive 2008/50/EC, 2018). One of the reasons for adoption of the directive is the poor air quality in many cities. In Europe, despites measures to reduce emissions, the acceptable standards of pollution are often exceeded. Especially in densely populated areas, citizens are exposed to high levels of polluting substances (EEA, 2018; Cariolet et al., 2018; Holman et al., 2015; Pasquier & André, 2017).

The European Directive regulates the pollutants for which there is the strongest evidence that they are harmful to health (WHO n.d.). These are particulate matter, nitrogen dioxide, ozone and sulphur dioxide. The most important sources of emission are road traffic, heating and supply of electricity (Airparif, 2014).

The list of potential health issues caused by exposure to air pollution is extensive, which corroborates the importance of the European Directive and its realisation. In an attempt to do so, many European cities have adopted policies to reduce concentrations of pollutants. One of these policies is the introduction of a low emission zone (LEZ). This study aims to assess the effectiveness of LEZ policies. More specifically, this study is an assessment of the LEZ regulations in Paris. The novelty in Paris' LEZ policy that determined this choice will be explained in section 1.3. First, section 1.1 explains an important feature in policies that address air pollution. This feature concerns a type of market failure: externalities.

1.1 Regulating an externality

Air pollution is a classic example of an externality. Nas (2016, p.47) defines externalities as: "costs and benefits imposed on third parties. They are unintentional, and their effects are not conveyed through the price mechanism". In case of air pollution, the emission of pollutants imposes external costs on society, such as health issues and environmental damages for which the polluter does not pay the price.

Externalities are one of the causes of market failure. Other causes are the presence of public goods and imperfect competition (Nas, 2016 p.29). Market failure can be problematic, because it leads to inefficient outcomes. In case of externalities, and thus air pollution, the inefficiencies result from overutilization of resources (Nas, 2016 p.48). The inefficient outcomes give cause to government intervention. Regulations that aim to achieve efficient outcomes address the overuse resulting from the externality.

As mentioned, traffic is an important source of air pollution. Therefore, regulations are often targeted at a reduction of traffic-related emissions. This reduction in emissions can be achieved by internalising the external costs into the price of the good (Nas, 2016 p.50). A number of alternative policies allow for internalisation of the external costs into the price of the good (Nas, 2016 p.52):

- the introduction of Pigouvian adjustments
- the use of tradable permits
- setting standards

Pigouvian taxes are assigned by government with the goal of controlling external costs (Nas, 2016 p. 52). An example is a policy that levies excise taxes on fossil fuels. The mechanism of the tax leading to a lower level of air pollution is that car owners will face a higher price for driving their vehicle, which should reduce demand and thereby lower traffic-related emissions. Another example of a Pigouvian adjustment is a price reduction for public transport (Panteliadis et al., 2014). In this case, the external *benefits* are internalized in the costs.

A system of tradable emission permits follows the same logic; the purchase of a permit increases costs of polluting. However, the price of a permit can fluctuate with regard to supply and demand, in contrast to a fixed excise tax.

The third and final category of policy alternatives is to set (technical) standards in order to reduce external effects. Compliance with the standard is enforced and monitored by government agencies (Nas, 2016 p.52). Examples of standards are the prohibition of diesel vehicles, or compulsory installation of a particle filter. Other policy examples are reductions in speed limits and implementation of a low emission zone. In case of a LEZ, the standard is defined by the category to which a vehicle is assigned. The more polluting the vehicle, the more it is likely to be regulated.

1.2 LEZs in Europe

To reduce emissions of polluting substances and to comply with the European Directive, many European cities have introduced traffic-related policies. Examples are improvement of traffic flows, price reductions for public transport and low emission zones in cities or towns (Panteliadis et al., 2014). The latter is one of the most popular strategies of European cities. This results in the creation of over 200 European LEZs in an effort to reduce air pollution levels (Cyrys et al., 2014; Holman et al., 2015; Panteliadis et al. 2014).

A low emission zone generally regulates the most polluting types of vehicles by preventing them from entering a specific road or area, or by charging to enter. Usually, the aim of LEZs is the reduction of exhaust emissions such as particulate matter (PM) and nitrogen oxides (NO_x) (Holman et al., 2015). Diesel vehicles emit more and are therefore regulated more strictly (Holman et al., 2015).

The first environmental zones in Europe were implemented in Sweden (Stockholm, Malmö and Goteborg) as early as 1996. Other countries and cities adopted LEZ frameworks about a decade later: Germany in 2007, Denmark, Amsterdam and London in 2008. The French introduced this policy relatively late; the first actual LEZ was introduced in 2015 in Paris (Holman et al. 2015).

Some European countries adopted a national framework for environmental zones, such as Germany and Denmark, while in other countries local politics determine the introduction of LEZ regulations (France, Italy).

1.3 The low emission zones in Paris

The agglomeration of Paris (Greater Paris) has over 12 million inhabitants, which makes it one of the densest populated areas in Europe. The city faces high levels of air pollution; concentrations of pollutants frequently surpass the acceptable health standards. According to Airparif, the regional body that monitors air quality in the department of Ile-de-France, over 100,000 inhabitants of the department are exposed to exceeding concentrations of particulate matter on daily basis (Airparif, 2018). According to the French quality objectives, to be achieved on the long-run, even 85% of the population in Ile-de-France is affected by exposure to high levels of pollution (Airparif, 2018). In Greater Paris, road transport alone causes 30% of particulate matter emissions and more than half of total nitrogen oxides emissions (Cariolet et al., 2018; Airparif, 2014). It is therefore rational that the regional government of Ile-de-France introduced policies that aim to decrease air pollution levels, by regulating traffic.

In this study, I will investigate the LEZ policy in Paris. Why Paris? Not only because improvement of air quality is an urgent matter, seen the size of the agglomeration and its population. Paris is selected because the LEZ policy has an interesting novelty: the environmental zone becomes effective in case of a peak in pollution. Contrary to 'regular' low emission zones, this policy only becomes operative when concentrations of pollutants are notably high. Hereafter, I will therefore explain the policies in Paris in broad outline.

In Greater Paris, two types of low emission zones are introduced. One is a continuous restriction of certain vehicles and the other becomes effective in case of a peak in pollution, which will be referred to as a smog scheme.

The city centre of Paris is a *Zone à circulation restreinte*, ZCR for short. This zone is located within the Boulevard Périphérique (the orbital road) and is effective on weekdays between 8 am and pm (Paris, n.d.). Crit'Air regulates the type of vehicles that are allowed to enter the city centre. It is a system of certificates which classifies vehicles on a scale of 0 to 5, 5 being the most polluting vehicles. Over the course of the next years, the requirements on vehicles will become increasingly strict (Paris, n.d.).

The smog scheme in Paris is called *Zone de Protection de l'air* (ZPA). The ZPA becomes effective when a peak in pollution is reached. The zone includes approximately 80 municipalities in Greater Paris that are situated within the second ring road A86.

The smog scheme entails two stages. The first stage is called *niveau d'information et de recommendation* (n1). It becomes effective when the concentration of pollutants exceeds the first threshold. During this stage, no traffic bans are in place, yet people are requested to reduce emissions. Moreover, n1 aims to inform those with poor health, to reduce their exposure to air pollution (Paris, n.d.). The second stage of pollution, *niveau d'alerte* (n2), is activated when the concentration of polluting substances surpasses a higher threshold. The regulations that become effective include traffic diversion, differentiated traffic and a price reduction for public transport (Paris, n.d.).

1.4 Relevance

It is surprising that the number of studies researching the effects of environmental zones on air quality is relatively low, seen the popularity of LEZ policies in Europe. The studies that did asses the effectiveness of LEZs showed contingent results. For instance, Panteliadis and colleagues (2014) examined the effects of the implementation of the LEZ in Amsterdam and found a substantial reduction of air pollution. However, Boogaard et al (2012) did not find significant results in the reduction of polluting substances in Amsterdam and other Dutch LEZs. Moreover, low emission zones in the form of a smog scheme are a scarce topic in academic literature.

With regard to the limited number of studies, their contingent outcomes and the relatively unknown effects of a smog scheme, one can conclude that the ZPA is a very relevant topic for further investigation. Moreover, it can be highly useful in both academic literature and for practical means.

1.5 Analysing the Paris' LEZ

In light of the practical and academic relevance, this study aims to investigate the effects of the smog scheme policy in Greater Paris. The policy has been gradually implemented since the mid '90s, yet no adequate research has been performed to study the effects of LEZ regulations on air pollution levels.

More specifically, this study aims to assess the activation of the smog scheme regulations that become effective when the concentration of pollutants exceeds the thresholds. The research question in this thesis reads:

What are effects of activation of the smog scheme regulations on ambient air quality in Greater Paris?

In order to study the air pollution in Paris, I will use data from Airparif. This body is one of the 18 French regional associations for air quality supervision (French: *Associations Agréées pour la Surveillance de la Qualité de l'Air,* AASQA*)*. It was founded in 1979 and works under supervision of the French Ministry of the Interior. Airparif is responsible for monitoring air quality in the region Ile-de-France and for information provision to inhabitants and authorities (Airparif, n.d-a.).

Airparif manages a network of about 70 stations throughout Ile-de-France (Airparif n.d.-b). The collected data concerns several types of pollutants, which can differ per station. Particulate matter and nitrogen dioxide are the most frequently measured pollutants. Hourly data is available since 1999.

For the analysis, a group of measuring sites will be selected based on the type of pollutants they report and based on their location. I will analyse concentrations of particulate matter (PM) and nitrogen dioxide. NO_x is the collective term for nitrogen oxide (NO) and nitrogen dioxide (NO_2). Particulate matter is a mixture of different components, containing particles of sulphate, nitrates, black carbon, and other components (WHO, n.d.). PM_{10} represents particles with a diameter smaller than 10 µm, subsequently $PM_{2.5}$ is used to indicate particles with a diameter smaller than 2.5 µm (Airparif, 2018; WHO, n.d.).

The selection of these two pollutants is based on the following motives. Firstly, I include these pollutants because of their proven adverse effects to human health. Secondly, because of the strong relationship between these pollutants and traffic emissions. Thirdly, because of data availability. The stations will be assigned to a ZPA group (stations that are located in the ZPA area and thus targeted by the smog scheme regulations) or a non-ZPA group (stations that are located outside of the ZPA boundaries).

I will use a regression analysis to estimate the effects of the activation of n1 and n2 on the pollutant concentrations. In the analysis, I will include weather variables to control for the confounding effects of meteorological conditions. Moreover, I include time dummies to control for a daily pattern in the development of pollutant concentrations.

The next chapter will discuss the case more in depth. It will explain the historical development of the policy and the current regulations and procedures. Moreover, it discusses the thresholds that determine activation of the smog scheme. Next, chapter 3 briefly discusses previous studies in the field of LEZ policies and their outcomes. More importantly, it explains the underlying mechanisms that relate the low emission zones to air quality. The fourth chapter presents the case selection and method of analysis. Next, I present the findings of the regressions and an analysis of the results. The final chapter provides a conclusion of the most important findings and an answer to the research question.

2. Description of the case

The aim of this chapter is to give insight in the administrative and historical background of the policy, in order to understand the concepts that are used in this study. First, I will give background information on the different authorities that are involved and on the historical development of LEZ regulations in Ile-de-France. The second section explains the ZCR policy and the Crit'Air certificates; the system that classifies a vehicle into categories based on how polluting it is. Next, I will explain the ZPA policy and discuss the regulations that n1 and n2 imply. This chapter will be concluded with an overview of the acceptable health standards provided by the European Directive and actual reported levels of air pollution.

2.1 Geographical situation

In order to explain the regulations that are relevant in the assessment of the ZPA regulations in Paris, I will briefly draw the administrative machinery of Paris and Ile-de-France.

Paris is situated in the region Ile-de-France. Concerning the surface, it is one of the smallest of the 13 French regions (excluding the overseas territories). Yet concerning the population it is the largest region with over 12 million inhabitants. This equals approximately 20% of the total population. The French regional governments are, among other things, responsible for infrastructure, secondary education and environment (Ministère de l'intérieur, 2018). This also includes air quality. Every region therefore has a regional association for the observation of air quality at its disposal. In Ile-de-France, this organisation is Airparif (Atmo France, n.d.).

Figure 1: Departments in Ile-de-France

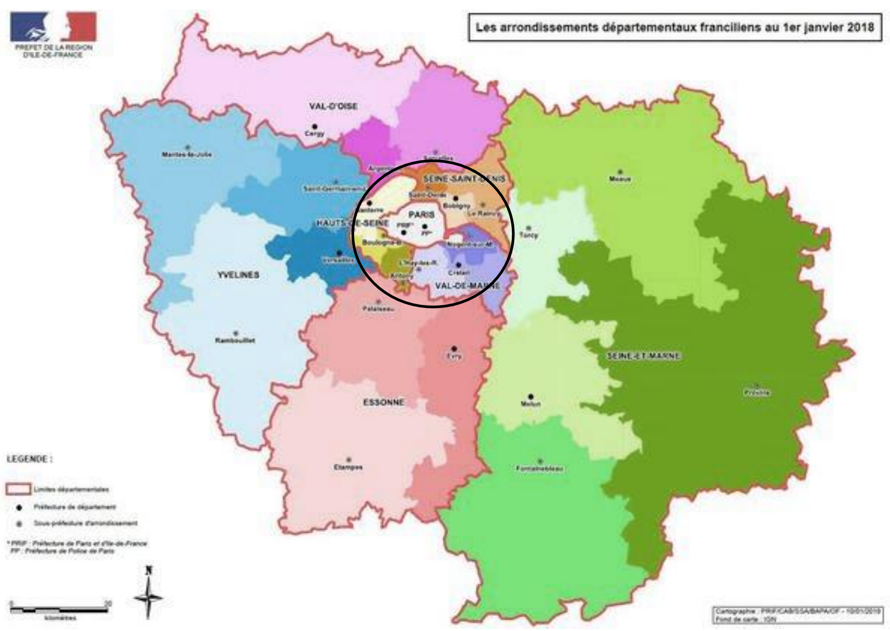
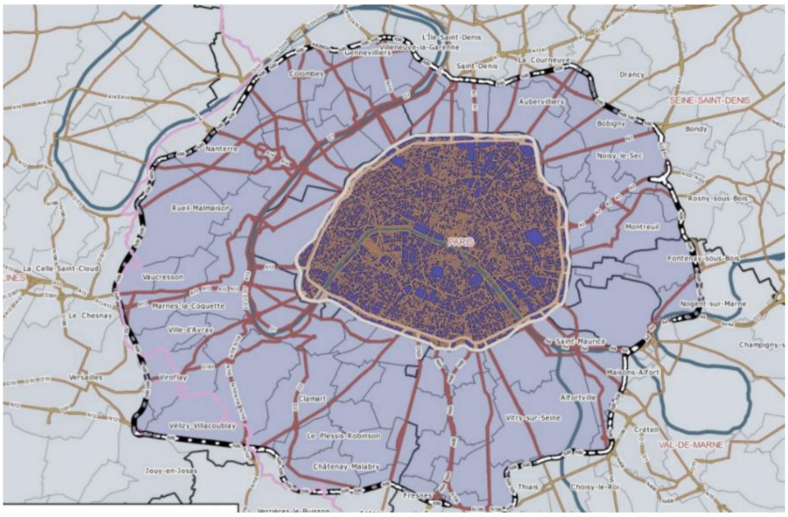


Figure 1 (Prefet de la région d'Ile-de-France, n.d.) shows the region Ile-de-France and its departments, in order to make clear which authorities are involved in the LEZ policy.

When talking about 'Paris' one could refer to different territories. Officially, Paris is only the area within the first ring road (Boulevard Périphérique), the white area in the centre of figure 1. This zone is a municipality, and simultaneously a department. I will refer to this zone as Inner Paris, or the city centre. Next, Paris could also be referred to as the 'metropolitan area of Paris'. This zone consists more or less of the inner city and the three departments enclosing the city centre (Seine-Saint-Denis, Val-de-Marne and Hauts-de-Seine). I will refer to this area as Greater Paris. In figure 1, Greater Paris is indicated in the circle.

The ZPA regulations apply to the area within the A86, the second ring road that was finished in 2011 (Arrêté inter-préfectoral 2016-01383, 2016). This area comprises a large part of Greater Paris (Le Parisien, 2011). Figure 2 shows both the Boulevard Périphérique around the centre and the A86 (DRIEE, 2017).

Figure 2: A86 Ring Road



2.2 Crit'Air certificates and ZCR in Paris

Before understanding the regulations of the smog scheme, it is important to be aware of other regulations in Greater Paris: the ZCR and Crit'Air. The latter is the classification system that determines the type of vehicles that are allowed to enter the city. This system is at the basis of both the ZCR and the n2 regulations of the ZPA. Therefore, an explanation of the classification and the ZCR precede detailed information on the smog scheme.

The ZCR is a continuous low emission zone that covers the area inside the Boulevard Périphérique (Paris.fr, 2019). The regulations of the ZCR in Paris are roughly the same as in other European LEZs: based on the type of vehicle (emission, age, type of fuel) some vehicles are not allowed to enter the environmental zone. In Paris, the traffic restrictions are effective between 8 am and 8 pm on weekdays (ANWB, n.d.; Paris, n.d.).

The restrictions are determined by a sticker system that is valid in France. This system is called *Certificat qualité de l'air,* Crit'Air for short. Figure 3 shows the Crit'Air categories; category zero refers to clean vehicles, such as electric cars. The fifth and final category indicates the most polluting vehicles (Ministère de la transition écologique et solidaire, n.d.).

Figure 3: Crit'Air classification stickers

The ZCR in Paris gradually tightened the standards for vehicles entering the city centre. A short overview of the subsequent phases of implementation (Paris.fr, 2019):

- September 2015: restriction of heavy duty vehicles that are more polluting than category 5
- July 2016: also private cars and light weight trucks more polluting than category 5 are prohibited (this concerns diesel vehicles built before 1997)
- July 2017: restriction of all vehicles in category 5, only categories 0 to 4 are allowed to enter the city centre.

In July 2019, a new phase will be implemented. From then on, only cars in category 0 to 3 are allowed to enter the city centre when the ZCR is effective (Paris.fr, 2019).

2.3 Development of ZPA regulations in Paris

The first policy in Ile-de-France aimed at a reduction of air pollution dates back to 1994 (Arreté inter-préfectoral 94 10504, 1994). The policy implies three levels of regulations, at three consecutive thresholds. The highest threshold is comparable to the n1 level in the current ZPA policy, while the first two stages concern only information provision to authorities. The observed pollutants were nitrogen dioxide, sulphur dioxide (SO_2) and ozone (O_3) (Arreté inter-préfectoral 94 10504, 1994). So far, the structure of the policy somewhat resembles the current ZPA legislation. However, an important difference between the 1994 and the current policy is the allowed concentrations of pollutants before regulations become effective; the threshold for the information provision in the mid 90's was 400µg/m3 of nitrogen dioxide, while nowadays this concentration level would activate the second stage (DRIEE, n.d.).

In 1999, a revision of the policy introduces the two levels of pollution as they are currently described: *niveau d'information et de recommandation* and *niveau d'alerte*. The concentration thresholds that determine the activation are comparable to the current policy of the ZPA. However, particulate matter is not yet one of the controlled pollutants (Arreté préfectoral 99-10762, 1999).

PM_{10} is included in the policy since 2007. The thresholds for particulate matter were 80µg/m3 on daily average to activate n1 and 125µg/m3 for n2 (Arrêté inter-préfectoral 2007-21277, 2007). For comparison: the current standards are set at 50 and 80µg/m3 respectively. This was determined when a modified policy was adopted in 2011 (Arrêté inter-préfectoral 2011-00832, 2011).

The current thresholds for n1 and n2 activation are based on the potential health effects they can bring about. The n1 concentration threshold can lead to temporary health issues for people with poor health, presumed that it is only short-term exposure. In case of short-term exposure, the n2 level could impose risks to the general health of the public (Arrêté inter-préfectoral 2016-01383, 2016).

Exceedance of the thresholds is not the only indicator for activation of the n1 or n2 regulations. Two extra conditions need to be met (Arrêté inter-préfectoral 2014-00573, 2014):

1) Either, at least 100km² of the total surface of Ile-de-France should be affected by the exceedance of a certain pollutant.
2) Or, at least 10% of the population within a department of the region should be affected

2.4 Current regulations and procedures

The modification of the regulation that was adopted in 2016 is the most recent one. It entails the procedures for introduction of the regulations, an elucidation of the maximum concentration before ZPA measures come into effect and an explanation of the specific type of regulations (Arrêté inter-préfectoral 2016-01383, 2016).

The procedure is put into action when Airparif, charged with the information provision of alarming concentrations of observed pollutants, informs the regional authorities. Airparif, subsequently, informs the public about the type of pollutant that surpasses the standards and the areas that are affected by the exceeding concentration. Moreover, Airparif informs people about the type of regulations that become effective and about potential health risks. Finally, a forecast is given about the expected development over the course of the coming days and the expected duration of the procedure (Arrêté inter-préfectoral 2016-01383, 2016).

In case the n1 threshold is exceeded, two types of recommendations become effective. Firstly, health recommendations. These include the advice to reduce outdoor physical activities and to circumvent the grand axis for travels by foot (Arrêté inter-préfectoral 2016-01383, 2016). Secondly, n1 includes behavioural recommendations (Arrêté inter-préfectoral 2016-01383, 2016). These include, among others:

- A reduction of speed limits of 20km/h in the entire department
- Circumvention of the agglomeration when using a motorized vehicle
- The use of public transportation or other modes of transport (cycling, walking etc.)
- Stricter traffic surveillance concerning speed limits

It is important to note that these measures concern recommendations, and thus that road users are not obliged to comply. Non-compliance does not lead to a sanction.

In case of n2, the above recommendations remain valid and a recommendation to limit the use of diesel vehicles is added (Arrêté inter-préfectoral 2016-01383, 2016). The following regulations are compulsory:

- Traffic differentiation: limitation of traffic within the A86 ring road, based on the Crit'air classification system
- Traffic diversion: heavy trucks that exceed a weight of 3.5 tons are diverted away from the A86 area.

Non-compliance with the Crit'Air-based compulsory regulations can lead to a fine. The amount depends on the type of vehicle: €135 for trucks and €68 for other vehicles (DRIEE, n.d.).

In case the traffic limitations within the agglomeration of Paris become effective, public transport is offered cheaper or free of charge. All measures apply starting from 05.30 am the next day, until midnight (Arrêté inter-préfectoral 2016-01383, 2016).

2.5 Allowed concentrations

In order to protect human health, the WHO and the EU have set standards for maximum concentrations of pollutants in ambient air. These standards form the basis for the French ZPA regulations. The levels for maximum concentrations before n1 or n2 regulations become effective are provided in the overview below (all concentrations are in µg/m³) (DRIEE, n.d.).

Table 1: ZPA thresholds

Pollutant	Average measured per	n1	n2
NO_2	Hour	> 200	> 400 and duration is 3 or more hours > 200 and duration is more than 2 days
PM_{10}	Day	> 50	> 80
O_3	Hour	> 180	> 240
SO_2	Hour	> 300	> 500 and duration is more than 3 hours

As explained in section 2.2, the thresholds are based on the potential health effects caused by exposure. Exceedance of the n1 concentration exposes the weak to temporary health issues. The n2 threshold can be harmful for general health of the public (Arrêté inter-préfectoral 2016-01383, 2016). Moreover, it has been explained that additional conditions need to be met for activation. The extra conditions concerning the surface or number of inhabitants exposed more or less implies that the threshold should be surpassed by more than one station. When this is the case for at least one pollutant, n1 or n2 will be activated.

Besides maximum concentrations, the European Directive prescribes a maximum number of days that these concentrations are allowed to exceed the standards and an annual average for NO_2 and PM_{10} (DRIEE, n.d.).

Table 2: EU and WHO limit values for the protection of human health

Pollutant	Average per	EU maximum averages	EU maximum annual averages	WHO recommendation for annual averages
NO_2	Hour	200, not to be exceeded > 18 hours per year	40	40
PM_{10}	Day	50, not to be exceeded > 35 days per year	40	20
O_3	Day	120, not to be exceeded > 3 days per year	-	-
SO_2	Hour	350, not to be exceeded > 24 hours per year	-	-

2.6 Reported concentrations

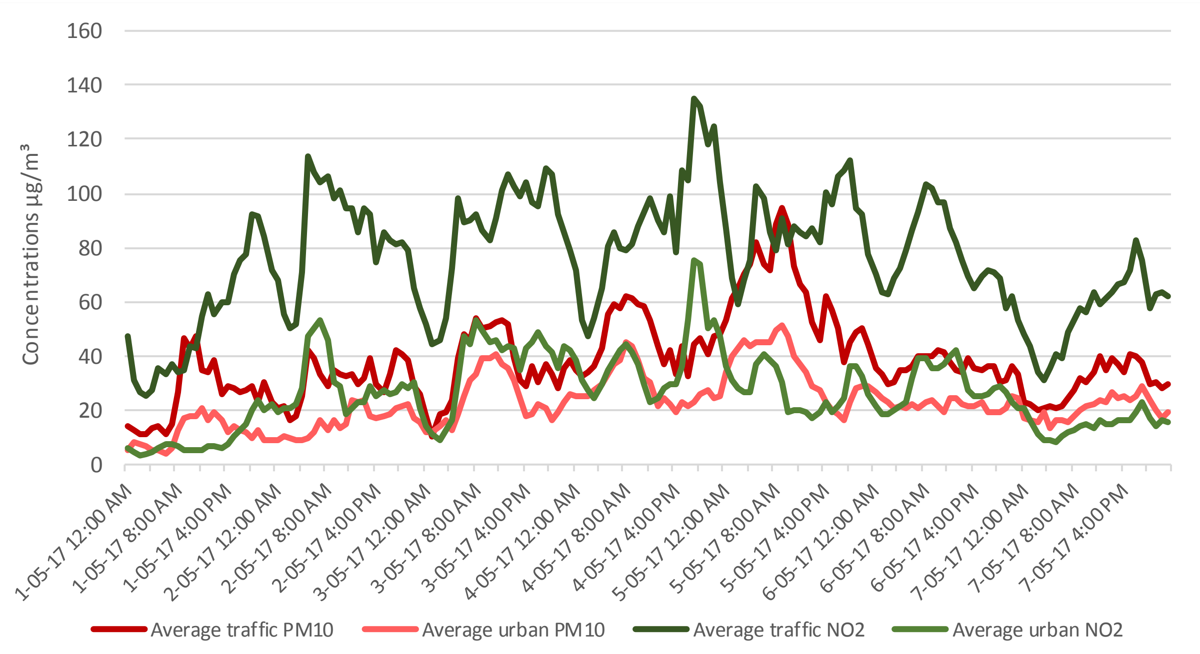
The final topic in this chapter is the actual status of air quality in Greater Paris. The thresholds for regulation are explained, but how to pollutants behave with regard to these thresholds? This section aims to answer this question by providing an overview of pollutant concentrations over the course of one week.

I start with an analysis of figure 4. The stations that are included are classified into two groups based on traffic intensity. This classification will be explained more profoundly in chapter 4, since it is an important feature of the case selection. For now, it suffices to understand that 'urban' stations face a lower traffic intensity than 'traffic' stations.

The concentrations of two pollutants can be observed in figure 4; the green lines represent nitrogen dioxide, the red lines represent particulate matter. This leads to four groups (urban/traffic and NO_2/PM_{10}) for which three stations are selected to calculate the average concentration. The three stations per group are the same ones as used in the regressions, selected because of their location, data availability and type of measured pollutants. This too will be explained in chapter 4.

The time span is one week in May (Monday until Sunday). This week is selected because no regulations were in place and because no data points were missing.

Figure 4: Average concentrations of PM_{10} and NO_2, traffic and urban ZPA stations



The measures of PM_{10} are substantially lower than the average concentrations of NO_2, but remember that the thresholds are not set at the same level of concentration. In fact, the threshold for nitrogen dioxide is not surpassed during this week in May. However, in the traffic stations the PM_{10} n1 threshold of 50 micrograms per cubic metre is surpassed frequently. On 5 May even the n2 threshold is exceeded. The urban stations, not surprisingly, report lower averages. They do not surpass the thresholds.

The traffic and urban stations seem to follow a similar trend. This is the case for both pollutants. A possible explanation is that emission of pollutants over the day follows a comparable pattern. This pattern shows a decrease of emissions at night, followed by an increase in air pollution during morning traffic hours. Especially the traffic stations report a sharp increase. Evening rush-hour however is less clearly visible.

6 And 7 May are weekend days. The decrease of emissions that one would expect on weekend days does not necessarily occur, since concentrations are not substantially lower than on other days of the week. However, the pattern over the course of these two days seems to fluctuate less, at least for particulate matter.

Now, let us zoom in on particulate matter and include some non-ZPA traffic stations. Figure 5 shows concentrations for particulate matter in traffic stations over the course of the same week in May. A1SD and AUT are traffic stations, located in the ZPA area. These stations report hourly averages that are characteristic of the traffic stations, since they often exceed the standards of 50 and 80µ/m³. People living nearby the main motorway around the centre of Paris are therefore often exposed to high concentrations of particulate matter.

RN6 and COU (the blue lines) are traffic stations as well, but located outside the ZPA region. These locations report lower hourly averages, but do seem to follow a similar trend as the ZPA stations. The pattern of decreasing concentrations at night and an increase during morning traffic hours is visible for both ZPA and non-ZPA stations.

What catches the eye is the peak of particulate matter in the station AUT. None of the other measuring sites reports such an increase in pollutant concentrations. This situation is a clear example of exceedance of the threshold, without activation of the n1 of n2 regulations. An explanation for this peak cannot be given with certainty. It might be related to the end of spring vacation or an exceptional incident, such as a fire.

Figure 5: Particulate matter, ZPA vs. non-ZPA

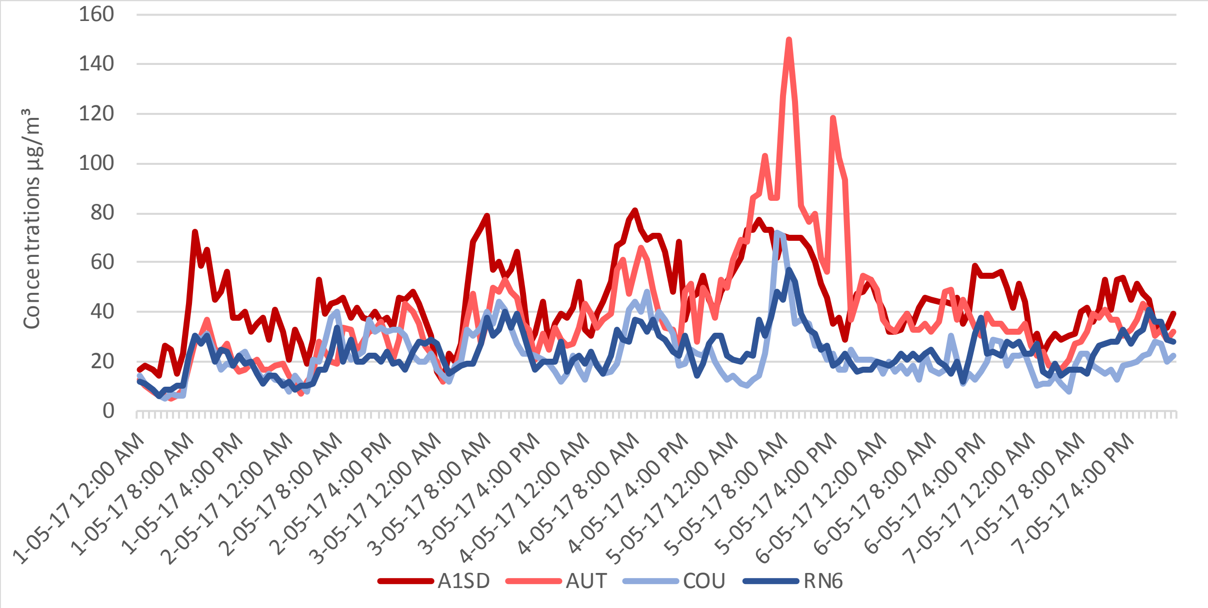
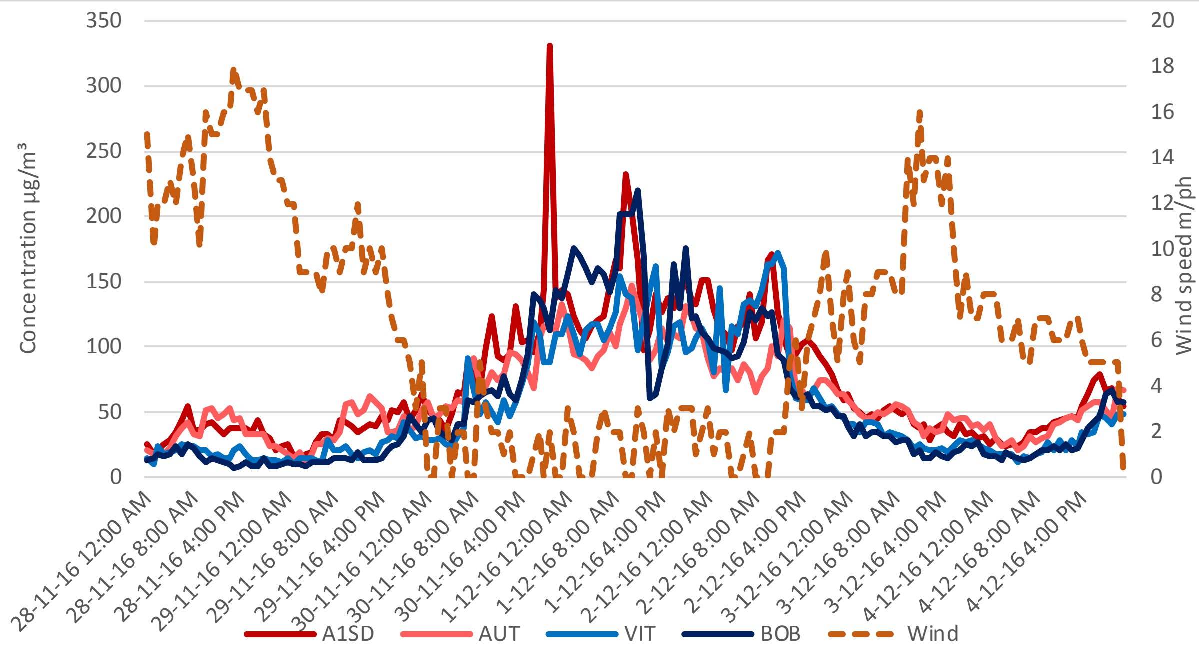


Figure 4 and 5 showed concentrations in a 'regular' week; no regulations were activated at that time. Figure 6 reports concentrations in a week with high levels of air pollution (28 November until 4 December 2016). Local emissions caused by traffic and combustion in combination with unfavourable weather conditions, lead to a considerable increase of pollutant concentrations (Airparif, 2016).

An increase of pollution is measured by all four stations between 30 November and 2 December 2016. During this week, n1 became effective on 30 November and n2 regulations on the two consequent days. Subsequently, a decrease of concentrations is visible on 2 and 3 December. The question is to what extent this is a result of the ZPA regulations. The answer is not straightforward since other factors affect pollution as well. To show this, wind speed is included in figure 6. A profound explanation of the effect of meteorological conditions will follow in chapter 3, though it is interesting to analyse the effect of a weather variable. The decrease in pollution coincides with an increase in wind speed. Therefore, as mentioned, the question remains to what extent lower concentrations of pollutants are a result of the ZPA regulations.

Finally, an exceptional peak in pollution can be observed at station A1SD, with a value of 331 micrograms per cubic metre. Again, a cause for this peak cannot be given with certainty. The uncommon peak is measured during one hour. This makes one wonder whether it could be the result of a flaw in the data.

Figure 6: PM10 in traffic and urban ZPA stations, including wind speed



A complete overview of n1 and n2 can be found in the annex.

2.7 Conclusion

The aim of this chapter was to give general information about the policy and it regulations. Firstly, this chapter covered the involved authorities and the historical development of the policy. Next, the regulations of the continuous LEZ in Paris were explained. It is important to keep in mind that the certificates of Crit'Air divide vehicles into six categories. This system enables authorities to differentiate traffic.

The regulations that become effective when n1 or n2 is activated were explained next. These include recommendations for n1, and two mandatory regulations in case of n2:

- Differentiated traffic based on the Crit'Air classifications
- Traffic diversion away from the area within the A86 ring road.

Subsequently, the procedures and thresholds that determine the activation were explained. What is important to remember, is that the n1 or n2 regulations do not simply become effective when one stations reports a concentration that exceeds the threshold. Activation of the regulations is related to a set of conditions, which are explained in section 2.3. To recap, these conditions imply, more or less, that several stations, instead of only one station, should report high concentrations before regulations come into effect. The actual activation does not happen automatically but depends on the information provision of Airparif to several authorities.

3. Theory

Studies on the effect of LEZs in Europe showed contingent results. In this chapter, I aim to give a brief overview of these investigations and their findings. Next, I will discuss theories that explain the potential effects of LEZs on ambient air quality. This chapter will conclude with hypotheses for the current study.

3.1 Academic literature on LEZ effects

Exposure to high concentrations of ambient air pollution is a problem for a large part of the European population. In an attempt to decrease air pollution and to improve human health, more than 200 low emission zones have been introduced in the past decades (Holman et al., 2015). Some of these zones have been studied in the academic literature. However, the effects of smog scheme regulations are still underrepresented in the literature. A large difference is that smog schemes should have a short run impact on air pollution levels, while in case of 'regular' LEZs the long run effects are relevant. I will therefore discuss some previously found results of environmental zones, but only briefly.

Panteliadis and colleagues (2014) have studied the impact of the LEZ in Amsterdam based on particulate matter and nitrogen dioxide concentrations. Their findings show a significant reduction in the concentrations of both pollutants, with larger effects measured at roadside stations than at urban background locations. The authors also calculate the traffic contributions to air pollution, by subtracting the background concentrations from the roadside concentrations. They, again, found statistically significant reductions: -5% for NO_2 and -6% for PM_{10}. Finally, Panteliadis and colleagues show that the effects were larger in the second phase (prohibition of Euro III vehicles without a diesel particulate filter) than in the first phase (prohibition of Euro 0, I and II). A potential confounder could be the compliance rate. Boogaard et al. (2012) show a higher compliance rate in the second phase (97%) than in the first phase (66%). The overall conclusion drawn by Panteliadis and colleagues (2014) is that the LEZ in Amsterdam decreased air pollution significantly for particulate matter and nitrogen dioxide.

Boogaard et al. (2012) explain that the policy in the Netherlands was mainly aimed at reducing emissions from old heavy-duty vehicles. They found a substantial decrease in heavy-duty vehicles with classification Euro 0 to III after implementation of the LEZ. Thus, the environmental zone implementation seems to be an effective strategy. However, the actual decreases in concentrations for particulate matter and nitrogen dioxide were not significantly different from the control locations. An explanation would be that trucks form only a fraction of total traffic. The authors therefore conclude that the reductions in air pollution are too modest to show significant effects of the LEZ.

A potential explanation for the different findings for the LEZ in Amsterdam is data collection. Panteliadis et al. used daily mean concentrations, while Boogaard and colleagues used six weekly samples.

Germany has a national framework for LEZs. It uses the European emission standards to classify vehicles into three categories. A sticker on the windscreen shows to which category the vehicle belongs. This somewhat resembles the French system, though in France there are six categories. The police, both in Germany and France, do enforcement manually (Holman et al., 2015).

Investigation of the German LEZs also led to varying results. For example, a study performed in Munich showed small reductions in air pollution levels (Holman et al., 2015). Fensterer and colleagues (2014) used long-term data and found large PM_{10} reductions (13%) when studying one roadside and one control station. Cyrys and colleagues found reductions of 5 – 12% when studying several stations in 2009 (Cyrys et al., 2009; Holman et al., 2015). Yet Cyrys and colleagues (2014) cast doubt on their previous findings, stating that meteorological year-to-year differences make it very difficult to accurately estimate the effects of LEZ implementation on air quality.

Holman et al. (2015) provide a meta-analysis of European LEZs and their effects. The authors stress that results of the effects are indeed mixed. This could be caused by the fact that countries or even cities have different frameworks for LEZ regulations. Moreover, compliance rates can be different per city and thereby influence the results.

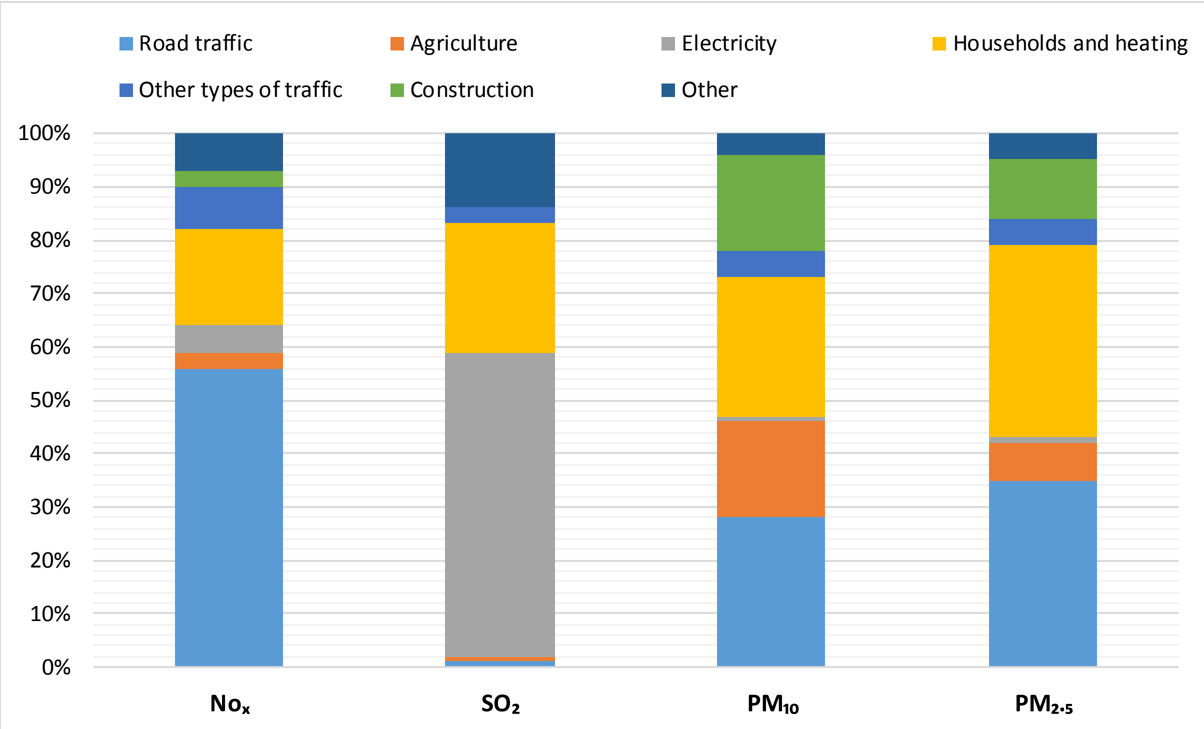
3.2 The underlying mechanisms

LEZs are being implemented in the effort to improve air quality and human health in densely populated areas. Even without clear results of LEZ introduction, we can theorise how LEZs are expected to impact air pollution. This section aims to answer the following question: how are air pollution and LEZs related? Three links will be discussed. Firstly, the share of traffic as a source of air pollution. Secondly, car fleet turnover and finally I will elaborate on a theory developed by Cariolet et al (2018) about a city's capacity to decrease emissions.

The first link between LEZ policies and air pollution is the fact that air pollution is caused for a considerable part by traffic-related emissions. This is obvious and might feel needless to mention. However, the share of traffic-related emissions is considerable and should therefore be explained explicitly.

Airparif provides data on the different sources of pollution in Ile-de-France, which is presented in figure 7 (Airparif, 2014).

Figure 7: Sources of emissions in Ile-de-France



The shares of road traffic in total emissions are 56, 1, 28 and 35 for NO_x, SO_2, PM_{10} and $PM_{2.5}$ respectively. This underlines the fact that traffic is an important source of nitrogen dioxide and particulate matter emissions. Sulphur dioxide however, is barely related to traffic-related emissions. Other important sources are households and heating, generation and supply of electricity and agriculture.

The second explanation of the relationship between air pollution and low emission zones concerns fleet turnover. Ferreira et al. (2015) state that the LEZ in Lisbon did not affect traffic volumes, but it did have an effect on the fleet composition. Cleaner cars would result in lower pollutant emissions. Pasquier & André (2017) confirm this theory. They explain a causal chain of three subsequent links that underly LEZ regulations. The first link runs from introduction of the LEZ to restriction of the most polluting vehicles (generally diesels and heave duty vehicles). Next, vehicle regulation poses several options to transport firms and car owners: to purchase a newer, cleaner vehicle that is allowed to enter the LEZ (car fleet turnover), to circumvent the LEZ (traffic shifting), or to use other types of transport (modal shifting). A final option is non-compliance. The likelihood of this choice depends among other things on the level of enforcement (Pasquier & André, 2017). Studies pointed out that car fleet turnover is the most plausible behavioural response to the implementation of a LEZ (Cyrys et al., 2014; Ellison et al., 2013).

Subsequently, the third link is that the fleet renewal should lead to a decrease in concentrations of traffic-related pollutants, since the use of cleaner vehicles will substitute the polluting vehicles. A reduction in air pollution should be the outcome, both within the zone and on the general axis leading to the environmental zone (Pasquier & André, 2017; Cyrys et al., 2014).

A scrappage scheme could accelerate the fleet turnover rate (Holman et al., 2015). In France, such a scheme was introduced on 1 January 2018. Car owners could receive a subsidy up to 2500 euros to exchange their older, polluting car, for a newer and cleaner version (DRIEE, n.d.).

Finally, the third link between air pollution and LEZs. Cariolet and colleagues (2018) argue that studies should not only take into account the policies and behavioural changes that could reduce air pollution, but should also take into account a city's ability to improve air quality. They state that the capacity of a city to decrease emissions, concentrations and exposure should be assessed when studying the effects of air quality actions plans such as the introduction of a LEZ.

The first factor is the capacity to decrease traffic-related emissions by proposing green alternatives to car usage. This includes the degree of 'walkability and bikeability' within a town or city as well as the public transportation network. An application of this theory to Greater Paris reveals that the capacity to decrease emissions is higher in Inner Paris and relatively low in the suburban area. This result is not surprising, since car usage is less attractive and less needful in the city centre (Cariolet et al., 2018)

The second factor is the capacity to decrease concentrations, which depends mainly on a city's ability to ventilate and disperse pollutants (Cariolet et al., 2018). Ventilation in the context of air pollution in its turn depends on wind speed, wind direction (Panteliadis et al., 2014; Cyrys et al., 2014; Airparif, 2018) and building density (Cariolet et al., 2018). Again, the application to Paris shows unsurprising results; Inner Paris has a lower capacity to decrease concentrations than the suburbs, because of the higher building density in the centre (Cariolet et al., 2018; DRIEE, 2018).

The final factor that influences the effects of air quality action plans is the capacity to decrease exposure of the population to air pollution. This factor is primarily important for the assessment of potential health improvements in view of LEZ introduction. Cariolet et al (2018) use the term 'exposure hotspots', which indicates an area where the inhabitants are frequently exposed to air pollution. These hotspots are located both in the city centre and in suburban neighbourhoods.

In short, Cariolet and colleagues look at invariant factors that have an impact on the effectiveness of air quality action plans. These invariant factors are generally based on man-made conditions in and around the city. However, air pollution is also strongly related to meteorological conditions, a factor that cannot be influenced by human decisions (on short term). The next section will therefore discuss effects of meteorology on air pollution.

3.3 Meteorological conditions

The effects of meteorological conditions are explained in the *Plan à protection de l'atmosphère* (PPA). The PPA is a multiannual framework that collects and coordinates all separate policies that aim to improve air quality in Ile-de-France. This PPA applies from 2018 to 2025 and has been preceded by two other PPA's (DRIEE, 2018).

The PPA provides an explanation of meteorological conditions and their effects on air pollution. According to the 2013 PPA, wind speed is strongly related to concentrations of pollutants (Prefet de la Region Ile-de-France & Prefet de Police, 2013). In case there is no wind, pollutants are barely transported through the air, which makes dispersion of pollutants very limited. Thus, wind speed has a negative relationship with air pollution. Next, rainfall. This also has a negative relationship with air pollution. It has the ability to 'clean' the atmosphere (Prefet de la Region Ile-de-France & Prefet de Police, 2013).

The statements of the French authorities have been confirmed by research. Many authors include weather conditions in their analysis of air pollution. For example, Cyrys et al. (2014) state that the effects on the long-run can be influenced by large year-to-year differences in meteorology. This can bias the findings in pollutant concentrations, and make it difficult to compare the concentrations before and after implementation of the LEZ. The confounding influence of weather conditions is confirmed by Nnenesi & Mokgwetsi (2009), who argue that wind direction and wind speed have a positive relationship with dispersion of pollutants and that temperature increases dilution of pollutants. Panteliadis et al. (2014) controlled for wind speed and wind direction, since they found that these weather conditions significantly affect pollutant concentrations. According to them, other conditions did not have a significant effect (temperature, precipitations).

3.4 Hypotheses

The goals of this study is to measure the effects of activation of the smog scheme regulations on air pollution in Greater Paris. Before discussing the hypotheses of this study, I will briefly discuss the expectations of the policy makers who designed the ZPA regulations.

As explained, the PPA forms a framework for several policies that are related to air quality. It explains that the introduction of the Crit'Air certificates allows for differentiated traffic, instead of the previous measure to alternate traffic based on number plates. In case of a peak in pollution, specific types of vehicles are not allowed to enter the ZPA zone within the A86 ring road. In other words, in case of an n2 activation, the ZCR that usually covers the city centre can be extended to the entire area within the second ring road, A86. The goal of this policy is not to contribute to a long-term improvement of air quality, but to limit the duration and the scale of a peak in pollutant concentrations (DRIEE, 2018).

The policy makers explain the expected effects of the ZPA regulations. More specifically, they explain the expectations of differentiated traffic. In case only Crit'Air 0 to 3 are allowed to enter the area within the A86 ring road (thus exclusion of Crit'Air 4, 5 and unclassified vehicles), the expectation is that the number of traffic kilometres will go down with 12%. This would lead to a reduction of 25% for the emission of PM_{10} and even 32% for NO_2 (DRIEE, 2017).

It is important to note that the expectations of the policy makers are based on the differentiated traffic regulations, that apply only when n2 becomes effective, and not when the n1 threshold is exceeded. The policy makers do not state a prediction of the effects of the health- and behavioural recommendations of n1.

Even though it is not stated explicitly, it seems as if the regulations for n1 do not aim to reduce the concentrations of pollutants, but rather to protect the weak from the consequences of exposure. Two arguments support this assumption. Firstly, the n1 regulations are only recommended, not mandatory. Secondly, the threshold for n1 activation is set at a level related to protection of those with poor health. Short-term exposure at n1 level is not necessarily dangerous to general health. This supports the idea that n1 is aimed at protection of those with poor health, instead of reducing exposure of the public in general. Moreover, no sanction is involved as long as the n1 regulations are effective. Besides the assumption that the aim of n1 is not to reduce air pollution, this is reason to believe that the effects of n1 will be zero. I therefore assume that n1 will not have a substantial effect on air quality in Paris, which leads to the first hypothesis.

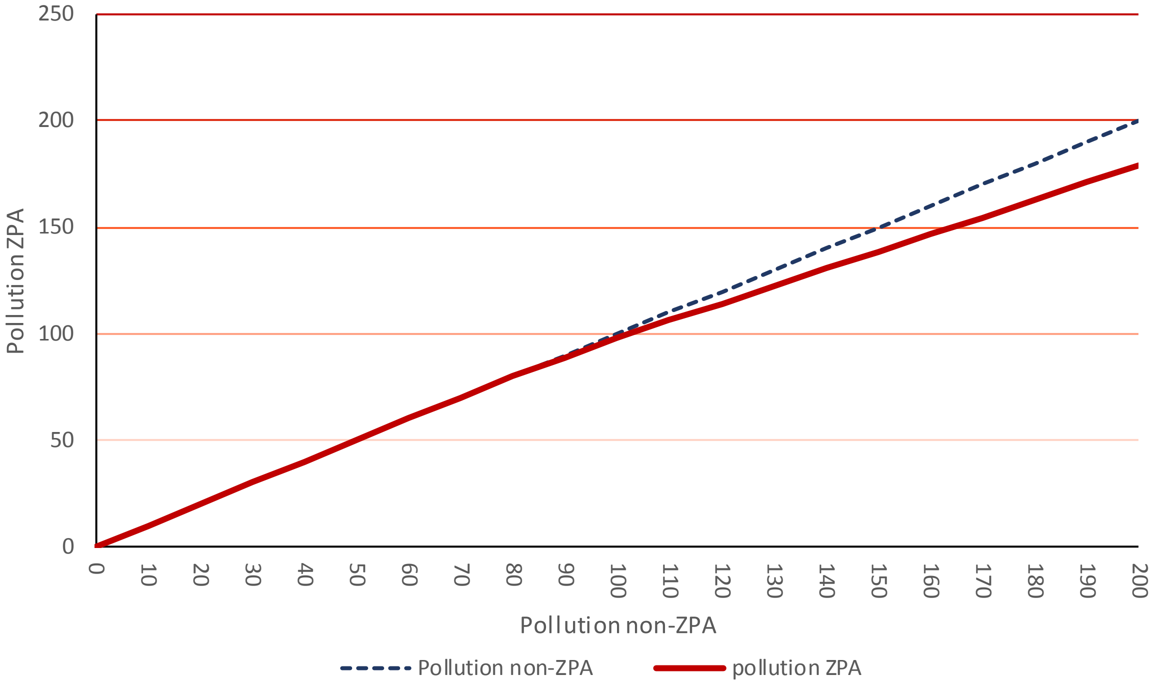
H_1: Activation of the n1 regulations in Paris has no effect on air pollution in the ZPA.

Concerning n2, the policy makers expect a substantial drop in emissions of particulate matter and nitrogen dioxide, which should lead to an improvement of air quality. Obliged traffic diversion away from the A86 area is another compulsory regulation. Moreover, enforcement of the n2 regulations is supported by penalties that should discourage car users of ignoring the Crit'Air requirements. Both measures contribute to the positive effect that the differentiated traffic has on air quality. This leads to the second hypothesis.

H_2: Activation of the n2 regulations in Paris has a negative effect on air pollution in the ZPA.

Figure 8 serves as an illustration of the hypotheses. The graph shows the concentration of a pollutant within the ZPA area (y-axis) with regard to a station outside of the zone (x-axis). The idea is that, as long as no regulation are operative, the concentration of a pollutant develops equally in both areas. When n1 becomes effective, both stations still report equal concentrations, because the expectation is that the activation of n1 regulations does not have an effect on the level of pollution in the ZPA area, compared to stations outside the ZPA area. When n2 becomes effective however, at a concentration of 80µg, the relationship between the two stations changes. The concentration of the pollutant within the ZPA area is expected to increase at a lower rate than the unregulated area outside of the A86 ring road.

Figure 8: Illustration of the hypotheses, regarding particulate matter



4. Research design

In order to measure the effect of activation of the smog scheme regulations, I will analyse data on pollutant concentrations in ambient air. The aim of this chapter is to explain the data collection, case selection and method of analysis that is used in this study.

4.1 Data collection

Airparif is the organisation that is charged with the observation of air pollution in Ile-de-France. The organisation disposes of data on different pollutants measured by 71 measuring sites in Ile-de-France. Data is available per station and on hourly basis, since 1999. The stations measure several pollutants, such as particulate matter and nitrogen dioxide, which are highly relevant for this study.

For information on the activation of n1 and n2, I will use the archive of Airparif. Their online information provision shows the exact dates of activation of n1 and n2, and it explains the conditions that have led to the activation (Airparif, n.d.-c).

Data on weather conditions is retrieved from Weather Underground, a company that provides worldwide weather data since the early '90s (Weather Underground, n.d.). The data offered by Weather Underground is very complete, since it includes data per half hour for wind speed, wind direction, temperature and other conditions. Only for precipitation, data is available per 24 hours.

4.2 Selection of pollutants

In line with other studies in the field of LEZ regulations (Boogaard et al., 2012; Panteliadis et al., 2014; Ferreira et al., 2015) I will include two important traffic-related emissions. The first pollutant is particulate matter. I will use data on PM_{10} concentrations and exclude $PM_{2.5}$ concentrations. This choice is based on data availability: PM_{10} concentrations are reported by most of the stations, whereas $PM_{2.5}$ levels are only reported by about ten measuring sites. The second investigated pollutant is NO_2, which is reported by most of the ZPA stations. However, the stations outside the ZPA area provide limited data on this pollutant. The pollutant NO will not be taken into account, since it is considered not to be a danger to human health.

The two other pollutants that are considered to have adverse effects on human health, ozone and sulphur dioxide will be excluded from this analysis. For ground-level ozone, this is because data is very scarcely available. Sulphur dioxide is unrelated to traffic emissions. It is therefore an irrelevant pollutant when studying the effects of LEZ regulations.

4.3 Selection of measurement stations

A network of 71 stations carries out the observation of air pollution (Airparif, n.d.-b). A large part of these stations is located within the ZPA area. A smaller part is located outside of this zone; these stations are called non-ZPA stations.

It is not possible to use data from all measuring sites. For example, because for some stations data appears to be unavailable during a considerable period. Moreover, not all stations report the pollutants that are relevant. In order to include only stations that are useful in this study, I have listed criteria for selection. These criteria and a justification of my choices will be discussed in this section.

<u>The station reports hourly concentrations without substantial gaps in the data</u>

10 of the 71 stations measure air quality over a longer period, in order to calculate annual averages. In view of the analysis of smog scheme regulations, I will focus on short-term changes in concentration levels. Therefore, I will exclude observations on annual basis. All remaining stations report concentrations every 15 minutes. Airparif converts these figures to hourly averages. Some of these stations however, report missing data during a substantial period. Those are excluded from the analysis as well.

<u>The station reports preferably both PM_{10} and NO_2, but at least one of these pollutants</u>

Not all stations report the selected pollutants particulate matter and nitrogen dioxide. Preferably, I select stations that report both pollutants. This is not problematic for stations located within the ZPA zone, however outside the ZPA data on these two pollutants is limited. It is not possible to select only stations that report both pollutants. Therefore I will select some non-ZPA stations that report either one of the polluting substances.

<u>The station is classified as either 'traffic' or 'urban'</u>

In order to prevent stations of different traffic intensity to be compared, I follow the classification of stations made by Airparif. This organisation divides the stations into four classes: traffic, urban, suburban and rural. 'Traffic' represents stations located near the main roads. 'Urban' is used for stations situated at secondary roads. The other two categories, 'suburban' and 'rural', are not suitable for this investigation, since they are exclusively located outside the ZPA zone, whereas the traffic and urban stations are represented both in and outside the ZPA area.

The station is not located within the ZCR area in Inner Paris

This is an additional criterium for the selection of stations within the ZPA. It does not affect the selection of non-ZPA stations, because of their location outside the LEZ areas of Paris. The criterium concerns the exclusion of stations in the centre of Paris, where the ZCR regulations apply. I made this choice to exclude potential bias caused by the ZCR regulations.

These criteria lead to a shortlist of suitable stations, classified into four groups: traffic PM_{10}, urban PM_{10}, traffic NO_2 and urban NO_2.

In the non-ZPA area, the number of stations that meet the criteria is limited to two stations per group. In the ZPA area, I have selected three stations per group that score best on the mentioned criteria. Moreover, I have taken into account the location of the station with regard to the city centre. If possible, I have selected stations located at different directions towards the centre.

Tables 3 and 4 provide an overview of the stations that are selected and their abbreviations, as used in the analysis.

Table 3: Traffic stations PM_{10} and NO_2

ZPA stations PM_{10}	Non-ZPA PM_{10}	ZPA stations NO_2	Non-ZPA NO_2
A1 Saint-Denis (A1SDp)	Route National 6 (RN6p)	A1 Saint-Denis (A1SDn)	Route National 6 (RN6n)
Boulevard Périphérique Est (BPEp)	Coulommiers (COUp)	Boulevard Périphérique Est (BPEn)	Monthléry (MONn)
Porte d'Auteuil (AUTp)		Porte d'Auteuil (AUTn)	

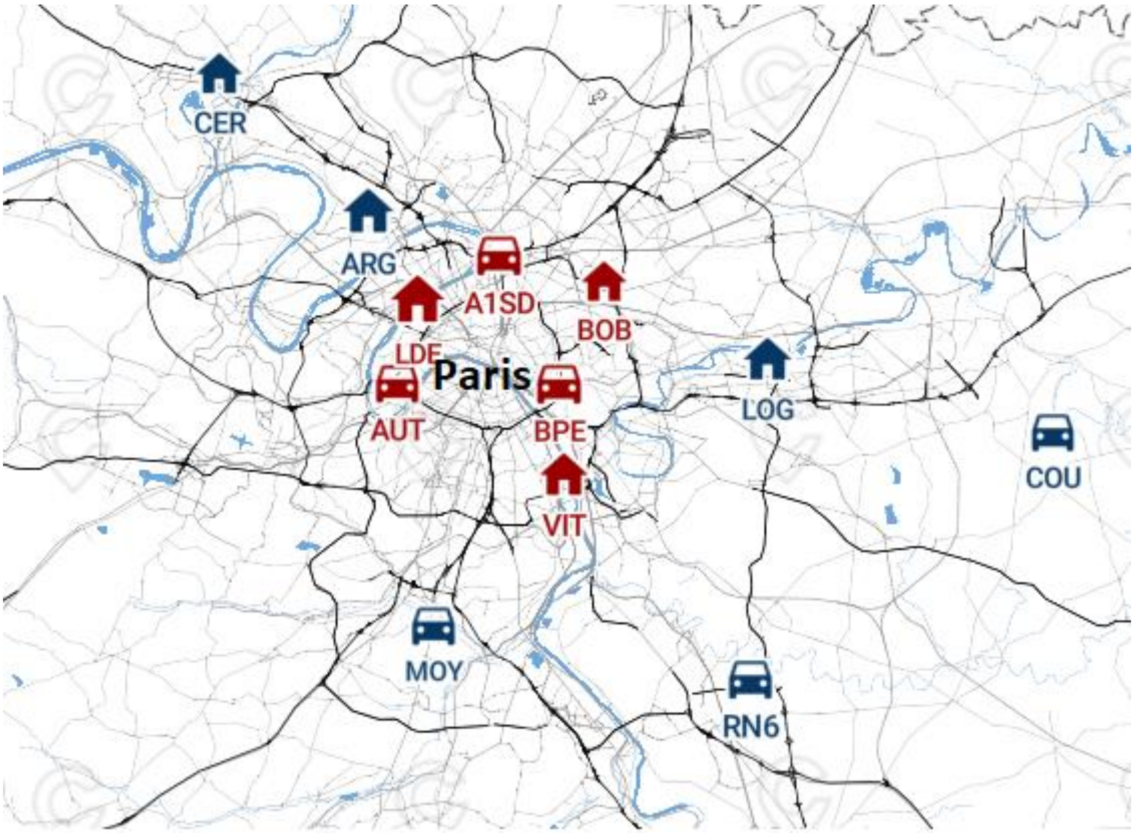
Table 4: Urban stations PM_{10} and NO_2

ZPA stations PM_{10}	Non-ZPA PM_{10}	ZPA stations NO_2	Non-ZPA NO_2
Vitry-sur-Seine (VITp)	Lognes (LOGp)	Vitry-sur-Seine (VITn)	Lognes (LOGn)
Bobigny (BOBp)	Cergy (CERp)	Bobigny (BOBn)	Argenteuil (ARGn)
La Défense (LDEp)		La Défense (LDEn)	

Figure 9 shows the location of the selected measuring sites. Red refers to the stations within the ZPA, blue refers to the non-ZPA stations. The different pictograms refer to the different groups; cars stand for traffic stations, houses for urban stations.

The period of interest in this study is 1 January 2016 to 31 December 2018. This period is based on the availability of full year data, since the introduction of the continuous low emission zone (ZCR) in the centre of Paris in September 2015.

Figure 9: Location of selected stations



4.4 Method of analysis

In this study, I examine the relation between pollution in ZPA stations and non-ZPA stations. More specifically, I would like to know whether this relation is affected by the activation of n1 and n2 regulations. Since the regulations of n1 and n2 only apply in the ZPA area, I expect to see a difference in and outside the ZPA zone concerning the development of the concentrations of pollutants when the regulations are put into action.

The analysis will be performed by OLS regressions, with the use of the following equation:

$$P_{z,t} = \alpha + \beta_1 P_{nz,t} + \beta_2 N_{1,t} P_{nz,t} + \beta_3 N_{2,t} P_{nz,t} + \beta_4 N_{1,t} + \beta_5 N_{2,t} + \beta_6 WS_t + \beta_7 TEMP_t + \beta_8 PREC_t + \varepsilon_t$$

The dependent variable P_z refers to pollution in the ZPA area, measured as the concentration in µg/m³. The ZPA stations are indicated by *z*. In addition, *nz* refers to non-ZPA stations. The subscript *t* stands for time. N_1 and N_2 are dummy variables that take the value 1 when the regulations are operative. Finally, the weather variables wind speed (*WS*), temperature (*TEMP*) and precipitation (*PREC*) are included in the regression.

Now, let me explain the expected effects of the variables in the equation. Starting with the variable $P_{nz,t}$, which represents the average pollutant concentration measured by the two selected non-ZPA stations. I expect to see positive coefficients.

Next, the interaction terms $N_{1,t}P_{nz,t}$ and $N_{2,t}P_{nz,t}$. The coefficients of these interaction terms indicate whether the relation between pollution within and outside the ZPA is affected by the activation of n1 or n2 regulations. In line with the hypothesis, I expect that $\beta_2 = 0$ and that $\beta_3 > 0$.

Next, the dummies for n1 and n2. These are included to point out the relationship between higher pollution levels and the n1 or n2 regulations. I expect positive coefficients for the variables $N_{1,t}$ and $N_{2,t}$.

Concerning the weather variables, I expect a negative coefficient in all regressions. This expectation is based on the findings of previous studies of the relationship between meteorological conditions and air pollution.

Time dummies will be added to the regression equation. The expectation is that emissions of pollutants follow a daily pattern, for instance due to traffic hours. It will be useful therefore to include time dummies that can control for a pattern if necessary.

4.5 Reliability and validity

Concentrations of particulate matter and nitrogen dioxide are important criteria for air quality. Several respected institutions such as the World Health Organisation and environmental agencies worldwide support this idea. The use of concentrations of pollutants is therefore a valid measure for air quality.

The use of an extensive dataset, including stations in both traffic and urban areas, contributes to the reliability of the findings. However, some factors limit the reliability of this study. Firstly because of the fact that data in the non-ZPA area is limited. Secondly, the number of days on which n2 has been activated in the period between 2016 and 2018 is restricted.

5. Empirical findings and analysis

This chapter presents the regression results. Before presenting the tables containing the findings of the regressions, I will discuss some descriptive statistics. This includes the mean, standard deviation and correlations of the investigated stations. Next, I will present and analyse the regression results for particulate matter and subsequently for nitrogen dioxide. The chapter concludes with an overview of the most important findings.

5.1 Descriptive statistics

The hourly data on concentrations of pollutants, collected over a period of three years, forms an extensive dataset. The reported concentrations fluctuate over time and per station. The tables below provide an overview of the descriptive statistics for every station. Following is a few observations with regard to tables 5 and 6.

Table 5: Descriptive statistics of the traffic stations

	Traffic PM10				
	Station	**N**	**Mean**	**Std. Dev.**	**Max.**
ZPA	**A1SDp**	25,633	42	19	331
	AUTp	25,547	36	18	253
	BPEp	25,599	30	17	210
non-ZPA	**RN6p**	25,730	26	16	235
	COUp	25,493	28	17	194

	Traffic NO2				
	Station	**N**	**Mean**	**Std. Dev.**	**Max.**
ZPA	**A1SDn**	26,041	82	26	232
	AUTn	25,717	89	32	325
	BPEn	25,668	66	34	279
non-ZPA	**RN6n**	25,595	44	22	174
	MOYn	22,838	65	30	283

Table 6: Descriptive statistics of the urban stations

	Urban PM10				
	Station	**N**	**Mean**	**Std. Dev.**	**Max.**
ZPA	**VITp**	24,515	21	13	172
	BOBp	25,289	20	13	220
	LDEp	21,264	21	13	185
non-ZPA	**LOGp**	25,100	19	12	194
	CERp	25,217	18	12	144

	Urban NO2				
	Station	**N**	**Mean**	**Std. Dev.**	**Max.**
ZPA	**VITn**	25,627	31	20	232
	BOBn	25,528	31	20	275
	LDEn	22,900	31	19	153
non-ZPA	**LOGn**	25,973	26	18	227
	ARGn	24,868	27	18	129

The number of observations per station counts approximately 25,000 figures per stations. The station in La Défense has misses some data points, though the number of observations is still more than 21,000.

When comparing the mean concentrations per group, it appears that the means within the groups of traffic stations vary quite a lot. In contrast, in urban station almost no variation is visible. A second observation, for both pollutants, the mean concentrations are considerably higher in traffic stations. This is not surprising since the intensity of traffic is higher in these locations, compared with the urban stations. Moreover, a difference can be observed between the ZPA and non-ZPA locations. The levels of pollutants is higher in the ZPA area than in the non-ZPA locations. The difference is substantial in traffic stations, but quite modest in the urban stations.

When looking at the standard deviations, it appears that the measurements are quite spread out from the mean. This concerns all groups. The maximum values are the highest in the traffic stations, as one would expect given the distribution of the means.

Table 7: Weather variables

Variable	N	Mean	SE	Max.
WS (m/h)	26,247	7.46	4.46	35
PREC (inch)	26,304	0.05	0.11	1.06
TEMP (F)	26,247	54.28	13.63	99

Table 7 presents an overview of the weather variables. Wind speed is measured as miles per hour. The mean of 7.46m/h is comparable to 12 kilometers per hour or to wind-force 3 on the scale of Beaufort. The variable precipitation has a mean of 0.05 inches per day, which equals a daily average of 1.25mm. Finally the variable temperature, measured in degrees Fahrenheit. The mean of 54.3 degrees Fahrenheit is equal to approximately 12 degrees Celsius. The maximum value of 99 is 37.5 degrees Celsius.

I return to the data on pollution measured in the station. Another interesting feature is the correlation between stations. Table 8 and 9 report these values for PM_{10} and NO_2 respectively.

Table 8: Correlation between stations for particulate matter

		Traffic ZPA			Traffic non-ZPA		Urban ZPA			Urban non-ZPA	
		A1SDp	**AUTp**	**BPEp**	**RN6p**	**COUp**	**VITp**	**BOBp**	**LDEp**	**LOGp**	**CERp**
Traffic ZPA	**A1SDp**	1.00									
	AUTp	0.6882	1.00								
	BPEp	0.7433	0.7144	1.00							
Traffic non-ZPA	**RN6p**	0.7166	0.6850	0.7433	1.00						
	COUp	0.6709	0.6354	0.6441	0.7447	1.00					
Urban ZPA	**VITp**	0.7194	0.7497	0.8150	0.7843	0.6806	1.00				
	BOBp	0.7564	0.7069	0.8226	0.7619	0.6656	0.8616	1.00			
	LDEp	0.6883	0.7986	0.7622	0.7289	0.6555	0.8452	0.8029	1.00		
Urban non-ZPA	**LOGp**	0.6676	0.6949	0.7400	0.7582	0.6755	0.8607	0.8389	0.7970	1.00	
	CERp	0.6734	0.6715	0.7475	0.7306	0.6069	0.8179	0.7952	0.7951	0.7587	1.00

The correlation between the traffic stations is approximately 0.7. This is comparable to the correlation between the traffic ZPA stations and RN6p (traffic non-ZPA). The other non-ZPA station is COUp, which reports lower values for the correlation (0.65). The urban stations are more strongly correlated; these values are roughly 0.8 to 0.86. In addition, the correlation between ZPA and non-ZPA stations is stronger when it concerns the urban locations (0.8). This coincides with the fact that the variation between means in traffic stations is larger than the variation between urban stations.

Table 9: Correlation between stations for nitrogen dioxide

		Traffic ZPA			Traffic non-ZPA		Urban ZPA			Urban non-ZPA	
		A1SDn	**AUTn**	**BPEn**	**RN6n**	**MOYn**	**VITn**	**BOBn**	**LDEn**	**LOGn**	**ARGn**
Traffic ZPA	**A1SDn**	1.00									
	AUTn	0.7000	1.00								
	BPEn	0.6065	0.5084	1.00							
Traffic non-ZPA	**RN6n**	0.6672	0.5984	0.5700	1.00						
	MOYn	0.3830	0.3520	0.2786	0.4348	1.00					
Urban ZPA	**VITn**	0.5458	0.5310	0.6072	0.4611	0.2370	1.00				
	BOBn	0.5754	0.4955	0.6635	0.4588	0.2248	0.8663	1.00			
	LDEn	0.6076	0.5574	0.7246	0.5859	0.3118	0.7598	0.8038	1.00		
Urban non-ZPA	**LOGn**	0.4968	0.4927	0.4154	0.4344	0.1987	0.8185	0.7805	0.6004	1.00	
	ARGn	0.6185	0.4725	0.6442	0.5098	0.2792	0.7750	0.8117	0.8500	0.6535	1.00

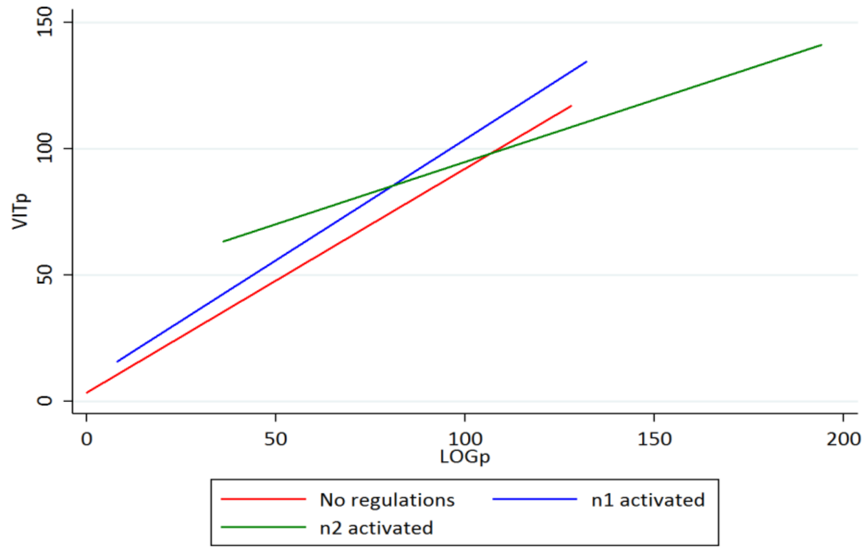
Next, the correlation between the NO_2 stations. What strikes is that in general the values are lower than for particulate matter. For example in the traffic stations the correlations are roughly 0.6 on average, compared with 0.7 for the PM_{10} value for correlation. The correlation between urban stations still is higher than between the traffic stations.

The non-ZPA station RN6n reports a lower correlation to the ZPA stations than was the case in table 8, with a value of 0.6 compared to roughly 0.7. The other non-ZPA traffic station is MOYn, which reports very low values for correlation with the ZPA traffic stations (approximately 0.35).

Figure 10 shows the fitted lines of the stations in Vitry-sur-Seine and Lognes, of which the latter is the non-ZPA station. These two stations are chosen based on their correlation of 0.86; one of the highest values of correlation between a ZPA and non-ZPA station.

The red line presents a fitted line of a scatter between the two stations when neither n1 nor n2 is activated. The scope of the line is almost 1. When n1 is activated, the coefficient of the fitted line changes only marginally as can be seen in the blue line. The green line indicates n2 activation. The coefficient has shifted; n2 is flatter than the other lines, which indicates that the concentrations of particulate matter in VITp increase more slowly than in the non-ZPA area.

Figure 10: Fitted line for VITp and LOGp



In view of this illustration, one might conclude that n2 has a negative effect on air pollution in the ZPA area, which is in line with the hypothesis. However, these descriptive statistics do not take into account the weather variables or time dummies. Therefore, it is too early to tell what the effects of n1 or n2 activation are.

In section 5.3, I will discuss the results of the regressions that include the control variables, to find the real effect of n1 and n2 activation. However, first it is important to check for autocorrelation. The dataset concerns time-series data, which is susceptible to autocorrelation. How to check for this issue and what to do about it will be explained in the subsequent section.

5.2 Autocorrelation

The regressions, performed as explained in chapter 4, lead to rather promising results. Most effects are strongly significant and negative, especially for n2 regulations. Based only on these findings, it would be logic to conclude that the smog scheme regulations have strong effects, both for n1 and n2. However, an important factor could bias the findings: autocorrelation. This occurs in a time series when the error terms are correlated, which conflicts with the requirement for error terms to be uncorrelated. The consequence of autocorrelation is that coefficients seem significant, while in fact they are not (Field, 2009).

To test for autocorrelation I use a Durbin-Watson test. The test provides a statistic with a value between 0 and 4. If the value is close to 2, one may assume that there is no autocorrelation.

A value lower than two is very common in time series, since it means that there is positive autocorrelation.

The result of the Durbin-Watson statistic on the regressions, is lower than 1. This means that the reported significant effects are clearly invalid and that it is important to control for autocorrelation in these regressions. In order to do so, I use the Prais-Winsten command, specifying the Cochrane-Orcutt option, which corrects for first-order autocorrelated error terms (Stata, n.d.). After running the regressions again, using this correction for serial correlation, the results have shifted. These results will be discussed in the subsequent section.

5.3 Results for particulate matter

Particulate matter is one of the pollutants for which there is strong evidence of its adverse effects on health (WHO, 2007). The concentrations in Paris often exceed the European standards, which should be reduced by the ZPA regulations. This section will first discuss the traffic results and next the results of the urban stations.

5.3.1 Traffic PM_{10}

Table 10 reports the results of the ZPA activation on concentrations of particulate matter in traffic stations Porte d'Auteuil, Boulevard Périphérique Est and A1 Saint-Denis.

Before analysing the findings, I should explain the abbreviation used in the interaction terms. As explained, PNZ stands for pollution in the non-ZPA stations. This is measured as an average of the two selected non-ZPA stations. The reason underlying the choice of using non-ZPA averages is that this would more accurately represent the level of pollution outside the ZPA area. The abbreviation PNZ is followed by 't' or 'u', which stand for traffic or urban respectively. Finally, the pollutant is included in the abbreviation: 'p' for particulate matter and 'n' for nitrogen dioxide. For example in table 10, this leads to the interaction term n1xPNZtp; n1 x the average of the non-ZPA traffic stations reporting particulate matter.

Table 10: Regression results PM_{10} in traffic stations

	AUTp		BPEp		A1SDp	
Obs	23,849		23,899		23,960	
R^2	0.092		0.095		0.180	
Dwatson	2.140		2.210		2.120	
Rho	0.822		0.852		0.733	
	Coef.	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
PNZtp	0.215***	*0.010*	0.199***	*0.008*	0.367***	*0.010*
n1xPNZtp	0.062	*0.035*	0.075*	*0.030*	0.190***	*0.035*
n2xPNZtp	0.073	*0.049*	0.097*	*0.042*	0.167**	*0.052*
n1	7.089***	*1.863*	8.163***	*1.628*	1.807	*1.854*
n2	17.764***	*4.598*	21.372***	*3.923*	13.697**	*4.839*

ws	-0.185***	*0.025*	-0.227***	*0.021*	-0.328***	*0.026*
temp	-0.084***	*0.020*	-0.217***	*0.019*	-0.200***	*0.016*
prec	-9.635***	*1.687*	-5.903***	*1.486*	-8.933***	*1.566*
T1	-2.508***	*0.276*	-2.275***	*0.231*	-3.104***	*0.306*
T2	-4.104***	*0.373*	-3.293***	*0.315*	-4.798***	*0.404*
T3	-4.644***	*0.438*	-3.300***	*0.372*	-4.709***	*0.463*
T4	-1.630***	*0.483*	-1.558***	*0.413*	0.112	*0.501*
T5	1.880***	*0.516*	1.197**	*0.444*	6.152***	*0.527*
T6	4.402***	*0.544*	3.091***	*0.470*	9.948***	*0.548*
T7	2.160***	*0.567*	3.116***	*0.492*	9.073***	*0.566*
T8	2.633***	*0.583*	3.675***	*0.507*	9.703***	*0.578*
T9	6.616***	*0.594*	5.172***	*0.517*	10.405***	*0.585*
T10	7.914***	*0.603*	5.280***	*0.524*	12.150***	*0.591*
T11	5.404***	*0.611*	4.523***	*0.532*	11.859***	*0.597*
T12	4.547***	*0.618*	3.495***	*0.538*	11.457***	*0.602*
T13	5.249***	*0.623*	3.568***	*0.542*	11.701***	*0.606*
T14	4.511***	*0.622*	3.393***	*0.543*	10.678***	*0.607*
T15	3.144***	*0.617*	2.922***	*0.539*	8.921***	*0.603*
T16	1.869**	*0.607*	1.963***	*0.529*	7.618***	*0.595*
T17	1.552**	*0.591*	1.929***	*0.514*	5.728***	*0.585*
T18	2.730***	*0.569*	2.372***	*0.493*	4.805***	*0.570*
T19	4.669***	*0.540*	4.036***	*0.466*	5.212***	*0.549*
T20	5.440***	*0.498*	5.052***	*0.427*	6.178***	*0.516*
T21	3.833***	*0.444*	4.490***	*0.378*	5.844***	*0.470*
T22	4.173***	*0.375*	3.451***	*0.317*	5.002***	*0.406*
T23	3.005***	*0.275*	2.218***	*0.231*	3.178***	*0.306*
_cons	33.536***	*1.205*	35.318***	*1.126*	39.385***	*1.021*

Legend: * p<.05; ** p<.01; *** p<.001

With the use of the Cochrane-Orcutt procedure, the Durbin Watson values are close to 2, which underlines the fact that these results are not biased by autocorrelation and thus that the significant effects are valid. This goes for all regressions that will be discussed in this section.

Let us start with a recap of the hypotheses before examining the findings in table 10. The expected effect of n1 activation is that the health- and behavioural recommendations have zero effect on air pollution. The expectation of n2 activation is a negative effect on pollutant concentrations. Given these expectations, the coefficients reported by the variables n1xPNZtp and n2xPNZtp in table 10 are surprising. Two out of three stations report positive and significant effects at both n1 and n2, which is contradictory to the hypotheses. The station in Porte d'Auteuil reports zero effect, which is closer to the expectations regarding n1, but not in line with the hypothesis for n2.

The weather variables seem to be in line with the expected effects. The coefficients of temperature, wind speed and precipitation are all negative and significant at the 1% level. This means that an increase of temperature, wind or rainfall will reduce the concentration of particulate matter in ambient air.

The time dummies report a clear pattern over the course of the day for all stations. At night the concentrations decrease and a sharp increase is visible between roughly T6 and T10; morning traffic hours. The evening rush hour is not as clearly observable, though a modest increase of the coefficients can be seen starting at 6pm.

5.3.2 Urban PM_{10}

Table 11 reports the coefficients and standard errors of the stations in Vitry-sur-Seine, Bobigny and La Defénse. The effects of n1 activation seem to be more or less in line with the hypothesis, but they deviate from the findings in the traffic stations. Two out of three stations report no significant effects for the interaction term of n1. The third station, Bobigny, notifies a positive effect, significant at the 10% level.

The variable n2xZNPup is in line with the hypothesized negative effect for, again, two out of three stations. One of these stations is Vitry-sur-Seine, where the effect is significant at the 1% level and rather substantial. The deviant station is Bobigny, where no effect is observed.

The weather variables and time dummies behave in the same way as in the regressions on traffic stations. A minor difference is that the evening traffic hours are not observable in the urban stations.

Table 11: Regression results PM_{10} in urban stations

	VITp		BOBp		LDEp	
Obs	21,294		22,645		18,984	
R^2	0.416		0.306		0.114	
Dwatson	2.150		2.120		1.850	
Rho	0.645		0.720		0.918	
	Coef.	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
PNZup	0.750***	*0.009*	0.668***	*0.010*	0.303***	*0.010*
n1xPNZup	0.018	*0.022*	0.062*	*0.026*	0.031	*0.026*
n2xPNZup	-0.264***	*0.036*	0.064	*0.040*	-0.111**	*0.037*
n1	5.676***	*0.946*	4.068***	*1.100*	1.181	*1.250*
n2	34.810***	*2.724*	14.198***	*3.007*	12.219***	*2.560*
ws	-0.132***	*0.014*	-0.137***	*0.015*	-0.046***	*0.013*
temp	-0.038***	*0.007*	-0.093***	*0.009*	-0.059***	*0.016*
prec	-5.731***	*0.744*	-3.665***	*0.880*	-3.121**	*0.958*
T1	0.136	*0.180*	-0.270	*0.178*	-0.057	*0.144*
T2	-0.013	*0.230*	-0.618**	*0.234*	-0.653**	*0.199*
T3	-0.360	*0.258*	-0.865**	*0.266*	-1.011***	*0.237*
T4	-0.026	*0.274*	-0.684*	*0.288*	-1.367***	*0.267*
T5	0.762**	*0.284*	-0.377	*0.303*	-1.209***	*0.290*
T6	1.595***	*0.290*	1.046***	*0.313*	-0.124	*0.307*
T7	2.725***	*0.294*	2.285***	*0.319*	2.133***	*0.321*
T8	3.034***	*0.296*	3.303***	*0.323*	4.999***	*0.330*
T9	3.399***	*0.298*	4.057***	*0.327*	6.662***	*0.336*
T10	2.830***	*0.301*	3.999***	*0.331*	6.688***	*0.343*
T11	2.278***	*0.304*	3.047***	*0.336*	5.919***	*0.350*

T12	1.538***	*0.307*	2.677***	*0.340*	4.977***	*0.357*
T13	1.359***	*0.309*	2.407***	*0.342*	4.338***	*0.362*
T14	1.626***	*0.310*	2.414***	*0.343*	4.209***	*0.363*
T15	1.554***	*0.308*	1.517***	*0.340*	3.293***	*0.360*
T16	1.191***	*0.305*	1.319***	*0.336*	2.998***	*0.353*
T17	1.038***	*0.301*	0.723*	*0.329*	2.654***	*0.340*
T18	1.387***	*0.295*	0.600	*0.319*	2.285***	*0.321*
T19	1.311***	*0.287*	0.744*	*0.307*	1.854***	*0.299*
T20	1.251***	*0.275*	0.913**	*0.290*	1.426***	*0.272*
T21	1.006***	*0.257*	0.984***	*0.267*	0.921***	*0.239*
T22	0.517*	*0.229*	0.928***	*0.233*	0.587**	*0.198*
T23	0.119	*0.179*	0.494**	*0.177*	0.258	*0.143*
_cons	8.708***	*0.509*	11.706***	*0.599*	16.298***	*0.934*

Legend: * p<.05; ** p<.01; *** p<.001

In short, the results in tables 10 and 11 do not show a univocal effect of the activation of n1 or n2 regulations on particulate matter concentrations. In traffic stations, positive coefficients dominate the findings, which is not in line with either one of the hypotheses. The urban stations do behave as expected, with zero effect at n1 activation and a negative effect on air pollution when n2 becomes operative. It should be noted though, that in all regressions the findings of one station deviate from the expected effects.

5.4 Results for nitrogen dioxide

Next, I present the findings of the effects on concentrations of nitrogen dioxide. These are comparable to the results in of urban PM_{10} stations: a dominant effect that is in line with the expectations and one station that reports somewhat deviating coefficients.

5.4.1 Traffic NO_2

The coefficients in A1-Saint-Denis are insignificant for both n1 and n2. BPEn behaves in the way that is hypothesised; zero effect for n1 activation and a negative effect for n2 activation. Porte d'Auteuil reports two negative coefficients, significant at the 10% level for n1 and at the 1% level for n2.

Table 12: Regression results NO_2 in traffic stations

	AUTn		**BPEn**		**A1SDn**	
Obs	21,402		21,426		21,665	
R^2	0.198		0.133		0.234	
Dwatson	1.890		1.990		1.910	
Rho	0.862		0.902		0.864	
	Coef.	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
PNZtn	0.228***	*0.011*	0.217***	*0.011*	0.175***	*0.009*
n1xPNZtn	-0.079*	*0.036*	0.063	*0.036*	0.048	*0.028*
n2xPNZtn	-0.225***	*0.068*	-0.184**	*0.065*	0.079	*0.053*
n1	15.121***	*2.883*	5.057	*2.940*	4.454*	*2.253*
n2	22.548***	*6.648*	27.641***	*6.591*	5.924	*5.145*
ws	-0.306***	*0.042*	-0.516***	*0.040*	-0.387***	*0.032*
temp	0.163***	*0.039*	-0.283***	*0.044*	-0.040	*0.031*

prec	-6.417	*3.411*	-5.623	*3.405*	-0.665	*2.659*
T1	-8.524***	*0.469*	-5.595***	*0.445*	-7.549***	*0.360*
T2	-14.683***	*0.639*	-9.252***	*0.612*	-12.521***	*0.490*
T3	-15.606***	*0.753*	-9.421***	*0.726*	-12.363***	*0.577*
T4	-8.491***	*0.842*	-5.509***	*0.818*	-4.739***	*0.646*
T5	5.882***	*0.938*	2.176*	*0.916*	7.991***	*0.720*
T6	15.423***	*1.018*	9.267***	*0.998*	16.586***	*0.782*
T7	13.949***	*1.060*	9.647***	*1.044*	17.357***	*0.815*
T8	10.094***	*1.077*	8.090***	*1.063*	16.921***	*0.829*
T9	8.502***	*1.082*	7.947***	*1.070*	15.539***	*0.833*
T10	9.339***	*1.092*	6.145***	*1.081*	14.080***	*0.840*
T11	11.434***	*1.106*	4.511***	*1.096*	13.262***	*0.850*
T12	11.745***	*1.117*	3.687***	*1.109*	13.719***	*0.859*
T13	13.501***	*1.128*	3.577**	*1.123*	14.162***	*0.867*
T14	15.355***	*1.135*	4.691***	*1.132*	14.680***	*0.873*
T15	16.624***	*1.140*	5.647***	*1.136*	15.846***	*0.877*
T16	15.964***	*1.148*	6.130***	*1.141*	17.285***	*0.883*
T17	16.449***	*1.147*	7.983***	*1.134*	18.458***	*0.881*
T18	20.100***	*1.110*	11.048***	*1.092*	20.031***	*0.852*
T19	23.764***	*1.034*	15.507***	*1.012*	20.545***	*0.793*
T20	22.590***	*0.924*	15.920***	*0.899*	19.763***	*0.709*
T21	17.887***	*0.798*	12.887***	*0.771*	15.830***	*0.612*
T22	14.366***	*0.657*	9.892***	*0.630*	12.608***	*0.504*
T23	9.483***	*0.471*	6.117***	*0.447*	7.343***	*0.361*
_cons	59.928***	*2.305*	67.977***	*2.606*	66.249***	*1.789*

Legend: * p<.05; ** p<.01; *** p<.001

The effects of some meteorological conditions on NO_2 deviate from the effects on PM_{10} concentrations. Precipitation seems to be uncorrelated with the concentration of nitrogen dioxide, in contrast to its effect on particulate matter. The effect of temperature is indistinct in table 12. However, all urban stations report negative and highly significant coefficients for temperature as will be shown in table 13. Wind speed is an important negative influence on nitrogen dioxide concentrations as well as it is on particulate matter.

5.4.2 Urban NO_2

The final group of regressions concerns the urban stations and their reported concentrations of nitrogen dioxide. The results are presented in table 13. Two out of three stations (Bobigny and La Defénse) notify coefficients that correspond with the hypotheses. In case of LDEn, this effect is significant at the 1% level. In Vitry-sur-Seine, a small effect can be noticed at n1, but no effects are measured for the activation of n2 regulations.

Table 13: Regression results NO_2 in urban stations

	VITn		**BOBn**		**LDEn**	
Obs	23,600		23,493		20,947	
R^2	0.460		0.443		0.395	
Dwatson	1.900		1.860		1.799	
Rho	0.769		0.775		0.881	
	Coef.	**SE**	**Coef.**	**SE**	**Coef.**	**SE**

PNZun	0.723***	*0.007*	0.712***	*0.008*	0.519***	*0.007*
n1xPNZun	-0.058*	*0.027*	0.040	*0.027*	-0.021	*0.033*
n2xPNZun	-0.015	*0.052*	-0.141**	*0.053*	-0.336***	*0.053*
n1	7.243***	*1.165*	3.949***	*1.183*	3.184*	*1.521*
n2	13.634***	*3.549*	18.110***	*3.607*	21.133***	*3.539*
ws	-0.296***	*0.019*	-0.227***	*0.019*	-0.146***	*0.019*
temp	-0.159***	*0.013*	-0.212***	*0.013*	-0.205***	*0.019*
prec	1.546	*1.185*	-0.353	*1.210*	-4.137**	*1.339*
T1	-1.737***	*0.219*	-1.841***	*0.221*	-1.976***	*0.204*
T2	-3.082***	*0.292*	-3.938***	*0.296*	-3.757***	*0.280*
T3	-3.377***	*0.337*	-5.568***	*0.342*	-5.131***	*0.332*
T4	-1.859***	*0.367*	-5.948***	*0.373*	-5.549***	*0.369*
T5	0.495	*0.388*	-4.781***	*0.394*	-2.971***	*0.398*
T6	3.393***	*0.406*	-1.806***	*0.413*	3.326***	*0.423*
T7	3.853***	*0.419*	-0.094	*0.426*	8.786***	*0.442*
T8	2.834***	*0.425*	0.273	*0.433*	10.751***	*0.453*
T9	1.582***	*0.429*	0.115	*0.437*	9.526***	*0.459*
T10	-0.672	*0.434*	-1.265**	*0.443*	7.024***	*0.467*
T11	-2.234***	*0.439*	-2.562***	*0.449*	4.940***	*0.476*
T12	-3.187***	*0.445*	-3.659***	*0.454*	3.722***	*0.484*
T13	-3.177***	*0.448*	-4.013***	*0.457*	3.646***	*0.489*
T14	-3.030***	*0.449*	-3.837***	*0.458*	4.139***	*0.490*
T15	-2.546***	*0.446*	-3.964***	*0.454*	5.509***	*0.486*
T16	-1.542***	*0.439*	-3.776***	*0.447*	8.102***	*0.476*
T17	0.007	*0.430*	-3.306***	*0.438*	10.290***	*0.461*
T18	1.711***	*0.420*	-1.898***	*0.427*	10.843***	*0.443*
T19	2.548***	*0.405*	-0.386	*0.412*	9.191***	*0.420*
T20	3.091***	*0.381*	1.874***	*0.387*	6.439***	*0.387*
T21	3.050***	*0.344*	3.430***	*0.349*	4.495***	*0.340*
T22	1.886***	*0.293*	3.024***	*0.297*	2.847***	*0.282*
T23	1.177***	*0.218*	1.425***	*0.221*	1.463***	*0.203*
_cons	22.010***	*0.842*	26.413***	*0.863*	25.449***	*1.137*

Legend: * p<.05; ** p<.01; *** p<.001

5.5 Conclusion of the findings

The table below gives an overview of the results that predominated in the tables of regressions. Before analysing these results, it is important to note that table 14 only shows the results that were reported by two out of three stations. The findings are thus not univocal.

Table 14: Overview of the predominant results

Niveau	Traffic PM_{10}	Urban PM_{10}	Traffic NO_2	Urban NO_2
N1 x P non-ZPA	Positive	0	0	0
N2 x P non-ZPA	Positive	Negative	Negative	Negative

Despite the deviating coefficients, three groups report effects that are in line with the expectations: urban PM_{10}, traffic NO_2 and urban NO_2. The coefficients reported by these groups indicate that activation of n1 regulations has principally zero effect. Moreover, they indicate that activation of the n2 regulations leads to a decrease of pollution in the ZPA area. These findings are not consistent with the coefficients reported by the traffic PM_{10} stations.

The positive effects for n1 and n2 activation are contrary to both the hypotheses and to the other findings in the regressions.

It strikes that the same stations report different effects when it concerns a different pollutant. What could explain this dissimilarity in the findings? One of the theories in chapter 3 explained that a city's capacity to decrease concentrations depends on wind and building density. Wind speed however, did not show a different effect in the deviating stations, therefore wind could not explain the different findings. Building density lies not within the scope of this study and it cannot be stated with certainty if this influences the findings. One would expect though, that stations located at the main motorway do not 'suffer' from building density any more than other stations. Maybe the ability to ventilate, as explained in chapter 3, is even higher on the motorway than in urban areas.

The theory on car fleet renewal in combination with the French scrappage scheme does not provide an explanation for this distinction either. In case Parisians drive newer cars, one would expect that these vehicles emit less of both types of polluting substances. Moreover, this theory cannot explain the difference in the findings between urban and traffic stations.

A possible explanation lies in the fact that nitrogen dioxide and particulate matter are to a different extent emitted by traffic, as explained in chapter 3. In Ile-de-France, traffic emits more than 50% of the total NO_2 concentrations compared to 28% of the total PM_{10} concentrations. The regulations that divert traffic away from the centre and that differentiate traffic could thereby have a larger impact on the concentration of nitrogen dioxide than one the concentration of particulate matter. This corresponds to the expectations of the policy makers. They foresaw a decrease in emissions of particulate matter of 25% compared to a decrease of 32% of nitrogen dioxide emissions. This underlines the fact that activation of the n2 regulations could have larger effect on concentrations of NO_2.

However, this theory cannot fully account for the different findings reported by table 14. This is because of two arguments. Firstly, the difference between the shares of traffic in the emission of NO_2 compared to PM_{10} is relatively small. This is not in line with the large differences between the outcomes of the regressions. Secondly, one would expect that the different effects would also be visible in the results of the urban stations. However, the results of the regressions do not provide convincing evidence for this theory.

Concerning the weather variables, these behaved as expected, at least concerning the regressions for particulate matter. Wind speed, temperature and precipitation reported negative effects, significant at the 1% level. When studying the effect of the meteorological conditions on nitrogen dioxide concentrations, drawing a conclusion less straightforward. Wind speed remains an important negative influence on pollution. Precipitation however, seems to be unrelated to the concentration of NO_2. The effect of temperature was negative and highly significant in the urban stations, but the effect was less clear in the traffic stations.

Even though it is difficult to reconcile the traffic PM_{10} findings with the other groups, it should be noted that most of the results are in correspondence with the hypotheses. The expectations that activation of n1 would not significantly improve air quality and that activation of n2 regulations would decrease pollutant concentrations in ambient air are demonstrated by the results. The presence of deviating effects in separate stations and in one of the four groups emphasises the importance of further research.

6. Conclusion

In this chapter, I aim to answer the research question of this study. I will do that by the hand of a summary of the case description and research design. Next, I will briefly recap the most important findings of the analysis. Thereafter I will give recommendations for further research in the field of LEZs and more specifically for the study of smog schemes.

Air pollution is a danger to human health, since it increases the risk of cancers, respiratory- and cardiovascular diseases. It is claimed to cause over 4 million premature deaths worldwide. In an attempt to decrease concentrations of polluting substances and in line with international legislation, many European cities have introduced low emission zones. The LEZ in Greater Paris is somewhat different, since it becomes effective in case of a peak in pollution. This smog scheme is the topic of interest in this thesis.

The research question as formulated in the introduction was the following: What are effects of the smog scheme regulations on ambient air quality in Greater Paris? The smog scheme policy is called 'ZPA' and is put into action when several measuring sites throughout the agglomeration report concentrations of pollutants that exceed the health standards. The policy entails two levels of regulations. The first is n1, which puts into action health- and behavioural recommendations. The second stage, n2, implies compulsory regulations: traffic differentiation and traffic diversion.

In line with the expectations of policy makers, the hypotheses were the following: I expected that activation of the n1 regulations does not have a significant effect on air pollution. For n2 however, I expected that activation of the regulations would have a negative effect on air pollution.

In order to research this, I have selected stations that report concentrations of NO_2 and PM_{10} and assigned them into two groups: ZPA stations that are located in the regulated ZPA area and a group of non-ZPA stations. The method of analysis concerns an OLS regression. In the regression equation, I have included variables for n1 and n2, three weather variables (wind speed, temperature and precipitation) and time dummies.

The results of the regressions were not univocal, though a dominant effect could be found. The majority of the stations reported, in line with the hypotheses, that the activation of n1 did not have a significant effect on air pollution. Activation of the regulations of n2 however, did seem to have a negative and significant effect on air pollution. Especially concerning the concentrations of nitrogen dioxide.

It should be noted that in every group, some stations deviated from these findings. Moreover, the results found in one group, the traffic stations reporting particulate matter, deviated from these findings. These stations reported positive effects for activation of both n1 and n2 regulations. Finding an explanation for this result is difficult, especially since it concerns only one group and one type of pollutant.

The deviating results in separate stations and in the traffic group make it difficult to answer the research question with absolute certainty. Obviously, the results allow believing that activation of the n1 regulations do not have any effect on the air quality in Greater Paris. As explained, I have not found an explicit statement on the expectation of n1 activation. However, it appears that the findings are in line with the goal of the policy makers to protect the weak instead of decreasing concentrations.

Moreover, the results of the regressions seem to prove that activation of the n2 regulations have some positive effect on air pollution in Greater Paris. This is an important conclusion. It underlines that activation of the n2 regulations is indeed effective: activation of the n2 regulations improve air quality. However, this improvement of air quality can differ per pollutant and per location throughout the agglomeration. The actual number of people that profit from improved air quality as a result of activation of the n2 regulations cannot be estimated without the findings of further research.

The reliability and validity of this study are not problematic, as explained in chapter 4. The use of particulate matter and nitrogen dioxide concentrations are an appropriate way to operationalise the concept of air quality, since these pollutants are two of the four most harmful polluting substances. In addition, the dataset is large and very precise, since it concerns hourly data. This contributes to the reliability. However, the limited number of days on which the n2 regulations were activated is a flaw in the reliability of this study. As indicated by the table in the annex, this comes down to seven days, spread over a period of three years.

Therefore, I would recommend addressing this limitation, by enlarging the period of interest. My choice for the period from 1 January 2016 to 31 December 2018 was because the ZCR could potentially bias the effect of the ZPA regulations. However, since this study was aimed at the assessment of short-term effects, I believe that this potential bias is limited. Extending the period of interest by the inclusion of 2015 would therefore be a reliable way of increasing the number of observations and thus to increase the reliability of the findings. The years before 2015 cannot be included however, because of a modification in the ZPA regulations, which leads to incomparable regulations of n1 and n2.

Moreover, in order to find more reliable and consistent results, the number of selected stations could be increased. In the ZPA area, I have now selected three stations per group, but this could be enlarged. In the non-ZPA area however, this might be difficult, since the number of stations reporting nitrogen dioxide or particulate matter is limited. Inclusion of another type of pollutant such as $PM_{2.5}$ as an addition to the dataset might be a way to increase the reliability of this study and to find results that are more consistent.

A final recommendation to study the smog scheme in Greater Paris is to assess the effectiveness of activation of the regulations separately. For both the n1 and n2 regulations, one could investigate to what extent activation of a separate regulation contributes to the overall effect. This is highly relevant for practical means, since it can contribute to an effective policy.

In short, it can be said that activation the n2 regulations do have a positive effect on air quality seem to be correct. To confirm these findings further research is needful, but at least this study is a first start in the investigation of smog schemes as a type of LEZ.

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Annex: overview of n1 and n2 activation

N1	N2
20 January 2016	
21 January 2016	
11 March 2016	
12 March 2016	
18 March 2016	
13 May 2016	
24 August 2016	
25 August 2016	
26 August 2016	
30 November 2016	
	01 December 2016
	02 December 2016
05 December 2016	
	06 December 2016
	07 December 2016
08 December 2016	
15 December 2016	
30 December 2016	
	21 January 2017
	22 January 2017
	23 January 2017
24 January 2017	
26 January 2017	
11 February 2017	
27 May 2017	
19 June 2017	
20 June 2017	
21 June 2017	
22 June 2017	
07 July 2017	
08 February 2018	
21 February 2018	
22 February 2018	
07 July 2018	
08 July 2018	
16 July 2018	
23 July 2018	
24 July 2018	
25 July 2018	
26 July 2018	
26 July 2018	
27 July 2018	
03 August 2018	
06 August 2018	
07 August 2018	