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Impact of bike sharing towards PM 2.5 pollution in 12 cities of Spain

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Furthermore, I would like to thank all the people who were part of my Erasmus semester in Bremen. I had the great pleasure to learn from great teachers as well and to make extraordinary friends from all over the world. This experience contributed to personal as well as educational growth.

Finally, I would like to thank Covid-19, which may seem a bit strange, but it has completely changed my life positively. I can proudly say that at the age of 23 I have contributed to the creation of a personal project, for which we will create a company imminently and that I have been able to become independent working with the salary of an intern.

ABSTRACT

The emissions of air pollutant PM 2.5 constitute great risks to health. Along in Europe, 400.000 premature deaths per year can be attributed to high exposures of fine particulate matter. The use of internal combustion vehicles contributes to % of this burden. Active modes of transportation like bike sharing systems (BSS) present a more sustainable mode of transportation within a city. Moreover, I found a lack of scientific research about PM 2.5 pollution in Spain and more concretely about the impact of BSS in Spain towards PM 2.5 pollution. Therefore, the aim goal of this study has been to determine if all variations of PM 2.5 pollution in 12 Spanish cities can be explained through the result of BSS implementations. The outcome has been obtained by using the Fixed Effects model, a type of panel data analysis. The results show that the implementations of BSS resulted in 14% less PM 2.5 pollution during the period 2008 until 2016. The outcome has been obtained by using the Fixed Effects model, a type of panel data analysis. My findings indicate that …

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1 INTRODUCTION

Ambient air pollution is seen around the globe as a major threat to health and climate. Not for no reason, The World Health Organization (WHO) estimates that worldwide 4.2 million premature deaths per year can be attributed to ambient air pollution in rural as well as in urban areas. This high mortality is due to an exposure to particulate matter of 2.5 microns or less in diameter which causes lung cancer as well as cardiovascular and respiratory diseases. (https://www.who.int/airpollution/ambient/en/)

A shift to more sustainable modes of transportation like public transport and active transportation like bike sharing can be a good solution to mitigate still high pollution levels in Europe were unfortunately 70% of European countries registered PM 2.5 concentration above the WHO Air Quality Guideline.

In the past decade, bike sharing has emerged globally as a great sustainable mode of transport, although the existence of its first generation in the 1960's did not become popular until the 21st century.

The main aim of this bachelor thesis is to determine through an econometric study whether the implementation of bikes sharing systems across the 12 biggest cities in Spain have contributed to a reduction in PM 2.5 emissions or if their implementation have not had any impacts in PM 2.5 pollution levels at all.

Therefore, by using the method of fixed effects, this bachelor's purpose is to compare pollution levels of PM 2.5 before and after the implementation of BSS in Spain's 12 biggest cities in combination with different parameters that will be explained in more detail in the data section.

During the bachelor Logistics and Maritime Business, I have learned in the subject *Transport Economics* the fact that transportation services generate environmental effects which contribute to premature deaths and shorten life expectancy as they cause noise, pollution, congestion, and accidents. These must be seen as external costs or negative externalities, that are not included in the price of combustion modes of transport generating indirect costs for society. Therefore, we discussed the importance of creating a tax imposition (Pigouvian taxes) equal to the monetary costs of the negative externalities, also called marginal external costs.

In addition, we learned that cities can have a monocentric (Madrid) or a polycentric (Barcelona) urban form, whereby a polycentric form involves a need of a good urban transport infrastructure to minimize external costs.
Furthermore, we discussed the trade-off between travel time versus monetary costs, whereby bicycles are the second cheapest mode of transportation after walking. Likewise, we specified the dominant modes of transport for every travel distance range. In the same way, *Martens, 2004* discovered that most bike users from Germany, Netherlands, and UK travel between 2 and 5 km to a public transport stop.

The bachelor's degree has given me a solid basis to carry out this paper. However, although I only had 2 courses that covered some knowledge about urban transport (last mile) and sustainable mobility, such a complex field of study is in some way new to me. Therefore, I will use this opportunity to prove myself that I am capable of performing a scientific investigation that in the end will hopefully contribute with new knowledge to these academic field and its community.

The case study is structured as follows:
A recent literature review can be found in the second section. In section 3, the goals for the scientific research are established, and in section 4 the methods and the data used to calculate the impact of bike sharing on PM 2.5 pollution are exposed. Section 5 show the obtained the results and section 6 the conclusions that can be extracted from the analysis of the results along with recommendations for public policy makers.

2 THEORETICAL FRAMEWORK

In this part, I will analyze scientific literacy about the origin, the evolution (trend) and the serious health impacts of PM 2.5 pollution as well as numerous studies and scientific papers that cover the fields of knowledge around Bike sharing and its impacts on pollution and health.

2.1 PM 2.5 POLLUTION

2.1.1 THE PROBLEM OF PM 2.5 POLLUTION

Particulate matter (PM) are inhalable and respirable particles composed of sulphate, nitrates, ammonium, sodium chloride, black carbon, mineral dust, and water. The concentration of an air pollutant like PM 2.5 is given in micrograms per cubic meter air or µg/m3.Particulates with a diameter of less than 10 microns (PM10), also called coarse particulate matter, include particles with a size smaller than 2.5 microns (PM2.5), fine particulate matter. According to the WHO, PM 2.5 constitute great risks to health, because due to their small size they can easily penetrate lungs and enter in the bloodstream.

In addition, *Dechezleprêtre, Rivers & Stadler, 2020* highlight also considerable economic impacts like reduction of life expectancy, increasing medical costs and a loss of productivity through working days lost across various economic sectors. (Dechezleprêtre, Rivers & Stadler, 2020)

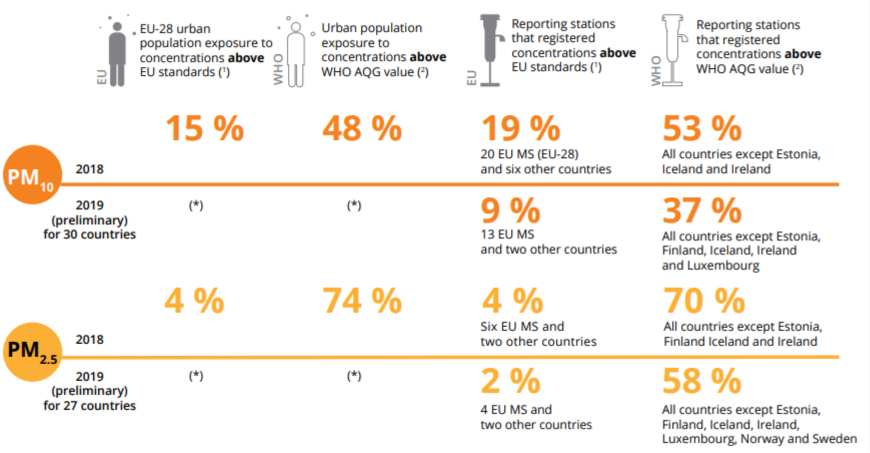
Boldo et al., 2006 carried out a Health Impact Assessment (HIA) of long-term exposure to PM 2.5 usind data of 23 European countries and the researchers concluded that 16.926 deaths from all causes, including 11.612 cardiopulmonary deaths and 1.901 lung-cancer deaths could have been avoided annually in every city if long-term exposure of PM 2.5 pollution levels decreased until 15 µg/m3. This reduction at 15 µg/m3 equals to a gain of life expectancy between 1 month and more than 2 years for an adult person at age 30.

An assessment carried out by the International Agency for Research on Cancer (IARC), which belongs to WHO, concluded in 2013 that particulate matter within in several other air pollution components, had a correlation with elevated cancer cases, particularly lung cancer. For this reason, the World Health Organization (WHO) established an Air Quality Guideline in 2005 with the goal to achieve low concentrations of particulate matter.
The WHO guidelines limit the exposure of PM 2.5 to humans at an annual mean of 10 µg/m3, while the 24-hour mean is set at 25 µg/m3. Afterwards the European Union approved in 2008 the *Directive 2008/50/EC* that binds legally every member state to limit its annual mean concentration of PM 2.5 at 25 µg/m3 as of today.

While most countries in the EU comply with the current target of 25µg/m3, only few stations located in countries like Finland and Iceland comply with the WHO air quality guideline. This can be seen in **Figure 1** which shows that in 2018, 4% of the European reporting stations have registered PM 2.5 concentrations above the EU standards (25 µg/m3), while 70% recorded concentrations above the WHO guideline (10 µg/m3).

In contrast, European air pollution stations have registered in 2019 less PM 2.5 concentrations. Although the general tendency of PM 2.5 concentration has fallen by 13% since 2009, Europe still faces a long way to reduce PM 2.5 concentration in compliance with the WHO guideline. (EEA No 09/2020, 2020)

Figure 1. PM 2.5 concentration of European reporting stations in 2018/2019

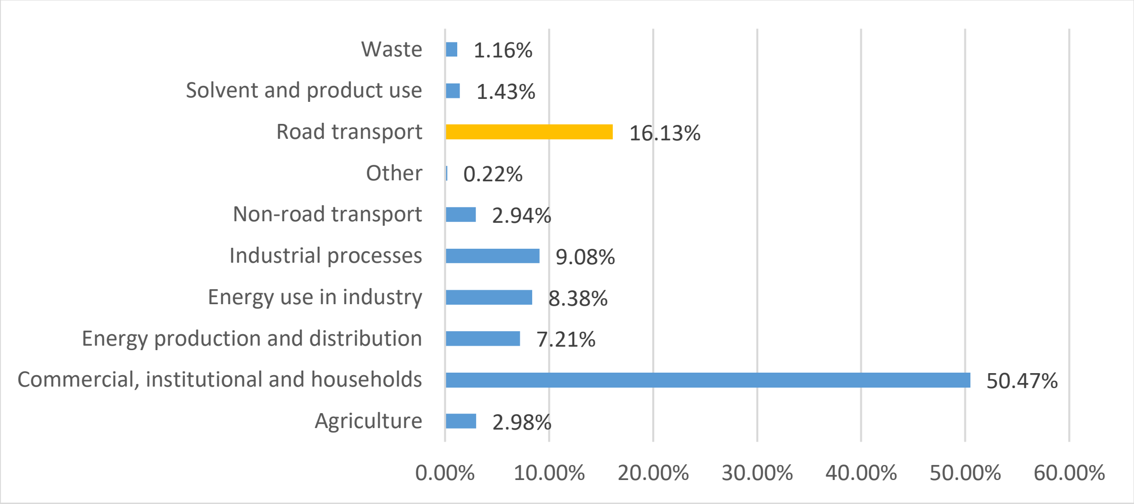


Sources: EEA No 09/2020 (2020)

2.1.2 ORIGIN OF PM 2.5 POLLUTION

Most of the particulate matter pollution levels can be attributed to human activities. Figure 2 shows the share of the sectors that contributed to PM 2.5 pollution in 2013, whereby road transport was the second sector that emitted more PM 2.5 emissions in Europe (16,13%). In addition, underline that commercial and institutional sectors as well as households are the biggest main pollutants contributing to half of all fine particulate matter pollution.

Figure 2. Sector share for emissions of primary PM 2.5 in 2013

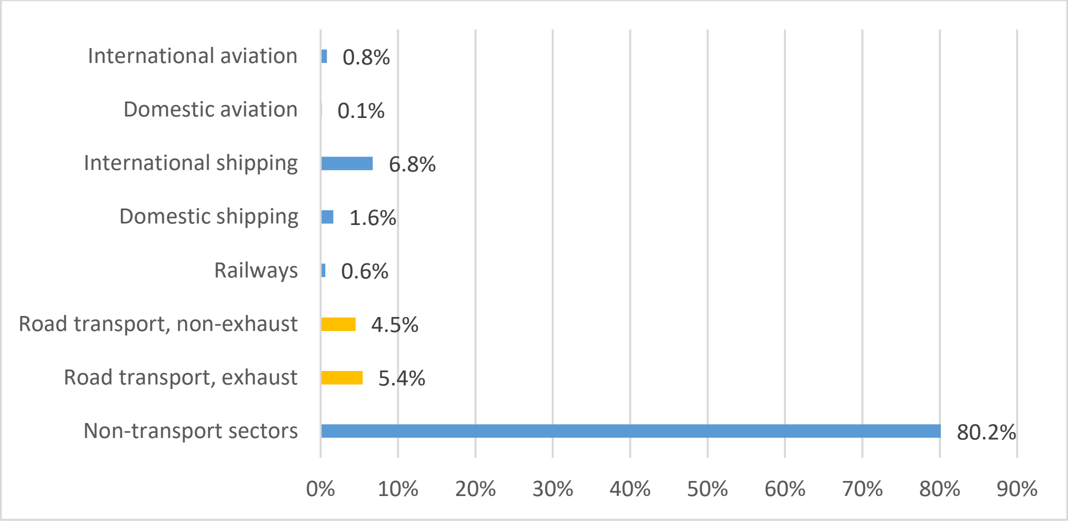


Source: Own elaboration based on EEA (CSI 003, APE 009, Published 27 Jun 2014)

According to a newer report of the European Environment Agency in 2019 (Figure 3), the transport sector produced 19,8% of total PM 2.5 emissions in the EU, in comparison with non-transport related sectors, 80,2% (EEA, 2019). Having in mind the data presented in Figure 2. this means that in six years, road transport has increased its share almost 4% in PM 2.5 particle emissions. Hence, the need to promote sustainable transportation has become even more important.

Analyzing the transport sector emissions of PM 2.5 in 2019 which account for 19,8%, road transport contributes with 9,89%, almost the half of total transport emissions in Europe and can be divided into exhaust (5,39%) and non-exhaust (4,5%) emissions.

Figure 3. Contribution of the transport sector to total emissions of PM 2.5



Sources: (EEA, 2019)

According to the ***EMEP/EEA air pollutant emission inventory guidebook – 2013*** exhaust emissions from road transport surge from fuel combustion of vehicles with internal combustion engines like gasoline, diesel, liquified petroleum gas and natural gas (Kouridis et al., 2014). On the contrary, non-exhaust particle emissions are generated by the wearing down of brakes, clutches, tires, and road surfaces and by the suspension of road dust (OECD, 2020).

Several papers underline that emissions from exhaust motors have decreased due to important technological improvements in recent years *(Amato et al., 2014).* Nevertheless, at the same time they emphasize the lack of improvement in reducing non-exhaust emissions, because few public policies target them specifically.
According to the report *Non-exhaust Particulate Emissions from Road Transport: An Ignored Environmental Policy Challenge*, this lack of improvement has increased the share of emissions from non-exhaust sources contributing about 85% of all PM 2.5 emissions from road traffic (OECD, 2020).

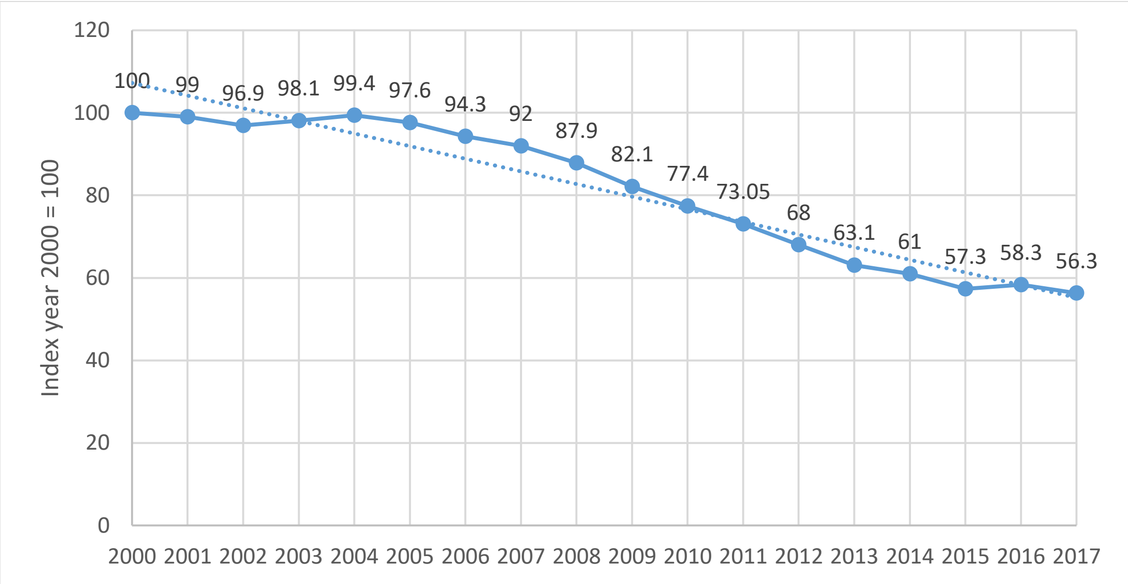
In addition, with the increasing tendency of future mass adoption of electrical vehicles (EV), countries around the globe will still have to deal with this environmental issue, because EV vehicles will only eliminate exhaust emissions, and will not provide any substantial benefits in terms of non-exhaust emissions reductions.
Moreover, researchers found that vehicle weight and non-exhaust emissions have a positive relationship, and because EV weight in average 24% more than conventional vehicles, EV's pollute only between 1 to 3% less in comparison with internal combustion engine vehicles (ICEV's). Therefore, there conclusion is that electrical vehicles may not have a big impact reducing levels of Particulate Matter (*Timmers & Achten, 2016).*

In this sense, as non-exhaust emissions are expected in future years to be responsible for the vast majority of PM emissions from road traffic and electrical vehicles will contribute very little to reduce PM 2.5 pollution levels, active transportation like bike sharing emerges as one plausible solution than can revert this harmful situation.

2.1.3 TRENDS OF PM 2.5 EMISSIONS IN EUROPE

Figure 4 represents the emission trends of PM2.5 from road transport among the 27 member states that compose the European Union between 2000 and 2017. Overall, fine particulate matter pollution levels have diminished between this period by 44%, despite the gradual increase in passenger and freight volumes.

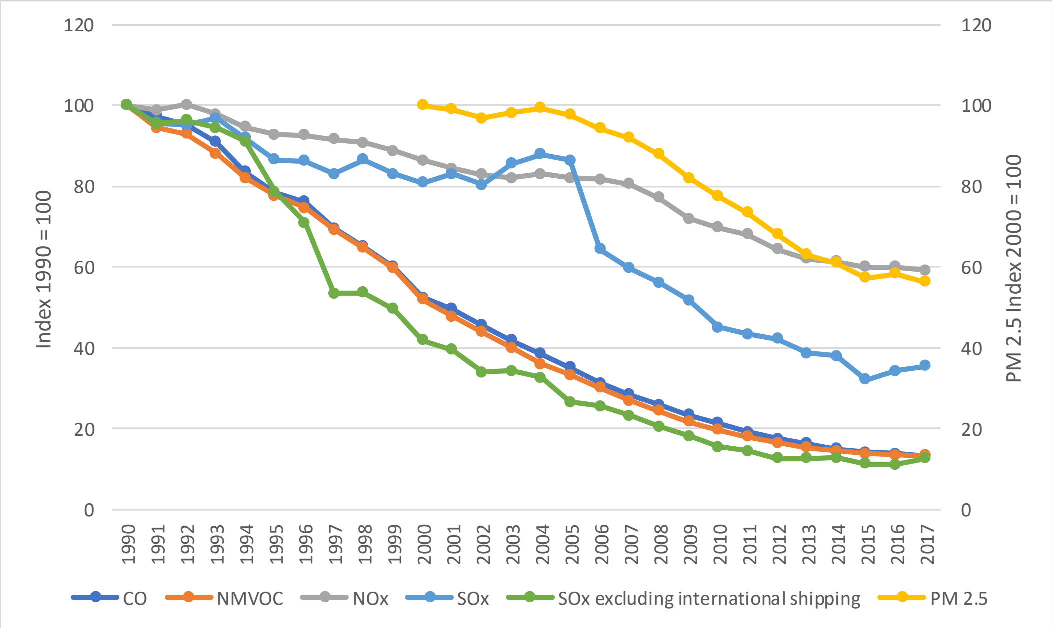
Figure 4. PM 2.5 emission trends of Road transport in EU-27 from 2000 to 2017



Source: Own elaboration based on National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) provided by European Environment Agency (EEA)

Even though, PM 2.5 emissions originated from road transport have been significantly reduced in the last decade, in comparison with other air pollutants there is still room for reducing even more pollution levels. *Figure 5* shows how much the main air pollutants in Europe have changed from 1990 to 2017, whereas the largest change in percentage has been produced by non-methane volatile organic compounds (NMVOCs), sulphur oxides (SOx) excluding international shipping and carbon monoxide (CO) reducing pollution about 87%. Sulphur oxides including international shipping (SOx) follows with a contraction of more than 60%, while nitrogen oxides (NOx) and PM 2.5 are the air pollutants with the lowest reduction: 41% and 44%, respectively.

Figure 5. PM 2.5 emission trends compared to other air pollutants from transport



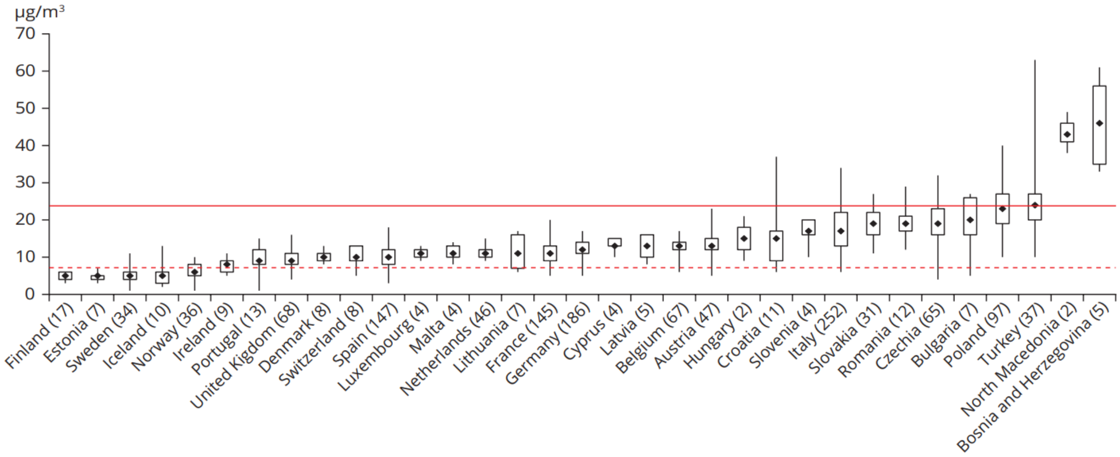
Source: Own elaboration based on National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) provided by European Environment Agency (EEA)

2.1.4 TRENDS OF PM 2.5 EMISSIONS IN SPAIN

Because the aim of this bachelor thesis is to focus on 12 cities located in Spain, it is important to analyze the current state of Spain's PM 2.5 concentrations.

Figure 6 illustrates that Spain figured in 2017 as the 11th country of Europe with the lowest PM 2.5 concentrations, being below the limit value set by EU legislation at 25 µg/m3 PM 2.5 concentration, marked by the upper continuous red line. Nevertheless, Spain is still slightly above the WHO guideline at an annual concentration of 10 µg/m3, marked by the discontinuous red line, as the rectangles that mark the 25th and 75th percentiles, are above such limits.

Figure 6. PM 2.5 concentrations of European countries in 2017



Source: EEA Report No 10/2019

2.2 BIKE SHARING

Bike sharing has been a hot field of study since several bike sharing systems were launched in the early 2000's. The growing awareness of negative impacts of combustion vehicles like congestion, noise, climate change and reduction of physical activity has attracted the interest of using and scaling active transportation in urban cities during the last years. (Fishman, 2014; Handy, van Wee, & Kroesen, 2014). However, it is the tendency of affordable payment and tracking technologies that have provided a basis for implementing successfully bike sharing programs around the globe. (Fishman, 2016)

In general, bike sharing offers a more alternative and sustainable transportation that results more convenient and attracts users to enlarge bicycle use in cities by integrating cycling into the urban and suburban transportation systems (Shaheen et al., 2010).

The principle of bike sharing is simple. Bike sharing users take a bike on an "as-needed" basis and do not need to take in costs of bike ownership. The system allows users to rent a bike through a member card and nowadays users can access via a mobile application in the phone. Researchers modelled bike sharing demand in Lyon and the results showed some important facts: The combination between Bike sharing and train was an important inter-modality (Tran et al., 2015).

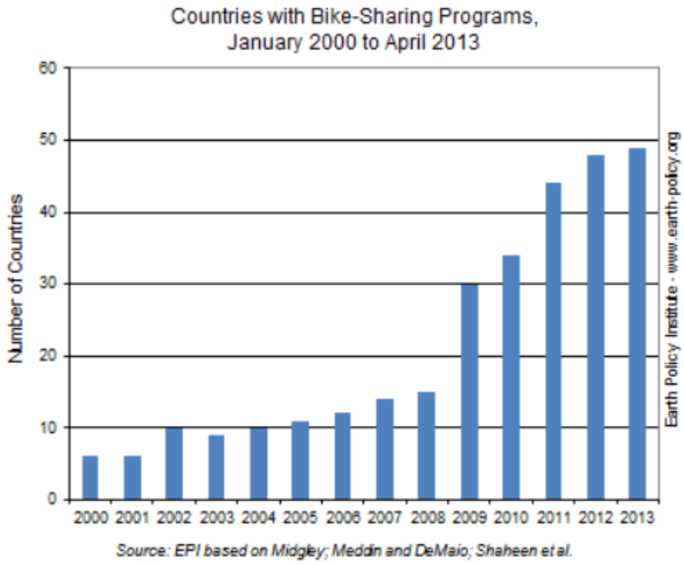
Because bike sharing has evolved during the past years it is important to explain the different generations in order to understand better the factors that have contributed to improve bike sharing systems and therefore it has become a mature mode of transport that has a positive impact on human health and environment.

To provide a good vision of most famous theories, I have structured the theoretical framework in subparts according to the previous literature.

2.2.1 EVOLUTION OF BIKE SHARING

Bike sharing adoption has been increasing worldwide. As the following chart shows, the presence of bike sharing systems has increased tenfold from 2000, where only 6 countries had BSS, to 2013 with almost 50 countries that launched their public bike sharing systems.

Figure 7. Countries with bike sharing programs between 2000 and 2013



2.2.2 GENERATIONS OF BIKE SHARING

Some researchers classified a decade ago the evolution of bike sharing into four generations (Parkes, Marsden, Shaheen, & Cohen, 2013) while Chen, F., Turoń, K., Kłos, M., Czech, P., Pamuła, W., Sierpiński, G. (2018) included a fifth generation.

In this part of the bachelor thesis, I will describe every generation of bike sharing showing the main characteristics and improvements every generation has contributed with.

2.2.2.1 FIRST GENERATION OF BIKE SHARING

The first generation of bike sharing, also known as “White bikes,” was launched in 1965 in Amsterdam and can be seen as the origin of public bike sharing systems.
Surprisingly, its origins cannot be attributed to public institutions wanting to promote a clean mode of transport. Rather, an environmental supportive organization called the Provos launched the “White Bike Plan” with 50 white bicycles as a solution to mitigate traffic pollution and accidents caused by motor vehicles in Amsterdam’s city center and as a revindication to condemn the bad service level of public transport (Martínez et al., 2019). The fact that every citizen could use them for free and the bikes were left without any security measure like a padlock, made them an easy target for thieves. Thus, many bikes where stolen and even thrown into the canals. (DeMaio, 2009)

2.2.2.2 SECOND GENERATION OF BIKE SHARING

The second generation of bike sharing, also known as deposit-coin bike sharing came almost 2 decades later in Denmark. Despite various small-scale implementations of public bike sharing programs in small towns of Denmark, Farsø and Grenå in 1991, and Nakskov in 1993 (Nielse 1993), a large-scale second generation begun in Copenhagen in 1995. This bike sharing system was the first one destined for a mass utilization and the first to incorporate docking stations distributed across the urban area. The system worked as follows: Users had to deposit a coin, concretely a 20DKK coin, in the docking stations to unlock the bike. Once the users returned the bike to a docking station, the coin was refunded, so the service was free of charge, too.
Although the bikes were secured through locks the anonymity of the users exposed the program to theft (DeMaio, 2009). Despite some defects of the second generation, several cities in Europe started to implement their bike sharing programs of the second generation.
(Bonnette, 2007) suggested that “both the first- and second-generation bike sharing schemes provided welcome opportunities to cycle but did not provide adequate support nor reliable service to alter motorized transportation choices and influence people to make significant changes.

2.2.2.3 THIRD GENERATION OF BIKE SHARING

Third generation bike sharing incorporated information technology to tackle previous problems like thefts and vandalism. The Portsmouth University in England was the first to be implemented in 1996. Students were able to unlock a bike via a magnetic stripe card. With the implementation of Lyon's public bike sharing system bike sharing in 2005, bike sharing begun to be a plausible alternative mode of transportation. including electronically locking racks, telecommunication systems, magnetic cards or smartcards and mobile phone access. Smart technology including magnetic cards, smartcards and mobile phone, is used to unlock and lock a bike of the docking stations.
Typically, bike sharing programs work as a membership service offering a free ride until a certain amount of time, for example 30 minutes, which is the case of Barcelona's Bike sharing system, Bicing.

2.2.2.4 FOURTH GENERATION OF BIKE SHARING

The fourth generation distinguishes from the third generation, because it incorporates smart bikes that are connected with an integrated traffic management system.
It provides the user real-time information through mobile apps about the current availability of bikes and parking slots and allows the users to even reserve a bike for a short period of time. Some BSS of this generation also include electric bicycles.
More important, this generation integrates a redistribution system of bikes to identify bicycle shortages and station overcrowding, in order to allocate bikes in a more efficient way.

2.2.2.5 FIFTH GENERATION OF BIKE SHARING

The fifth generation of bike sharing system distinguishes mainly from the fourth on the fact that this generation does not need any docking stations to lock or unlock the bike. Instead, the bike can be parked on the street within an allowed area established by the organization.
After doing a research about cities that already had an ongoing BSS of fifth generation, CHEN et al., 2018 listed the main advantages and disadvantages according to two examples in China and Poland.

Advantages

- **Availability of bikes:** As docking stations do not exist, users can park the bike anywhere in the city. This makes it a lot easier for users, as they do not need to search for a docking stations with available parking slot.

- **No dependence of the user's destination route**: Users can choose almost without restriction where to leave the bike and therefore their destination route is not being altered, because they do not need to find where the nearest docking station is located.

- **No problem with overcrowded docking stations:** Because docking stations do no exist, the problem of overcrowded docking stations vanishes.

Disadvantages

- **Theft of bikes:** Dockless BSS are more vulnerable to thieves than previous generations because they are not locked with a docking station.

- **Poor technical condition:** While users can choose freely where to park their bicycle, it is more complicated for operators of the BSS to repair bicycles since bikes are distributed in different locations across the city. Hence, users find more bikes with poor technical condition.

- **Parking bikes in the wrong places:** One predicament is leaving bicycles in unauthorized places, like parking in the middle of a pavement, hampering other users of road infrastructure to pass by. On the other hand, parking bikes in rarely frequented locations, so other users of the BSS will not likely use them, is another example of parking bikes in the wrong places.

Figure 8. Generations of bike sharing systems

First Generation: White Bikes (or Free Bikes) Systems

- **Components**
  - Bicycles
- **Characteristics**
  - Distinct bicycles (usually by color)
  - Located haphazardly throughout an area
  - Bicycles unlocked
  - Free of charge

Second Generation: Coin-Deposit Systems

- **Components**
  - Bicycles
  - Docking Stations
- **Characteristics**
  - Distinct bicycles (color or special design)
  - Located at specific docking stations
  - Bicycles have locks

Third Generation: IT-Based Systems

- **Components**
  - Bicycles
  - Docking Stations
  - Kiosks or User Interface Technology
- **Characteristics**
  - Distinct bicycles (color, special design, or advertisements)
  - Located at specific docking stations
  - Bicycles have locks
  - Smart technology is used for bicycle check-in/checkout (mobile phones, mag-stripe cards, or smartcards)
  - Theft deterrents (program specific; members are required to provide ID, bankcard, or mobile phone number to identify users). Failure to return bicycle incurs charges to recover bicycle cost and may also include high punitive costs. Non-members are generally required to pay a large deposit to ensure bike return, under risk of losing their deposit.
  - Programs paid for as a membership service, typically free for the first specified time interval with gradually increasing costs enforced.

Fourth Generation: Demand Responsive, Multi-Modal Systems

- **Components**
  - Bicycles
  - Docking Stations
  - Kiosks/User Interface
  - Bicycle Distribution System
- **Characteristics**
  - Distinct bicycles
  - Programs may include electric bicycles
  - Specific docking stations that are more efficient (mobile, solar powered, etc.)
  - Improved locking mechanism to deter bicycle theft
  - Touch screen kiosks/user interface
  - Bicycle redistribution system
  - Linked to public transit smartcard

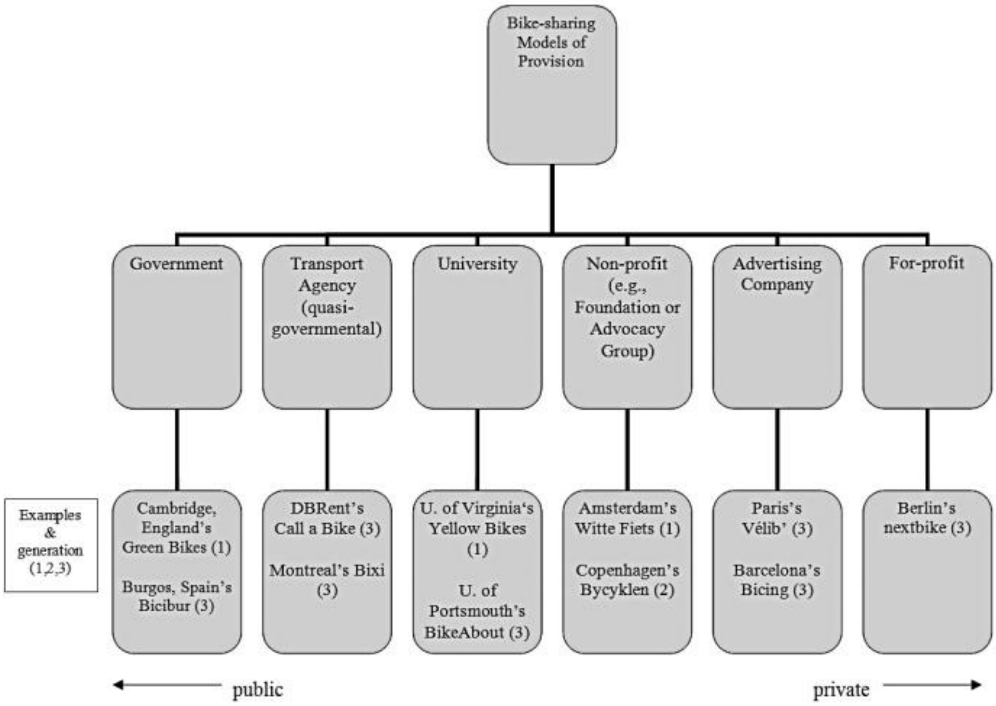
Source: (Shaheen et al., 2010)

2.2.3 BIKE SHARING PROVIDERS AND BUSINESS MODELS

Given the success of third generation bike sharing systems, different bike sharing providers have arisen. In this section we will resume them to further understand which model of provision applies for Bicing, Barcelona's public bike sharing system.

As shown in Figure 4. they can be classified into government, transport agency, university, non-profit, advertising company and for-profit models (DeMaio, 2009).

Figure 9. Models of Provision



Source: (DeMaio, 2009)

The (local) **government model** presents two variants. The first possibility is that local public authorities design and act as operators of the bike sharing system and thus provide the service directly to bike sharing users. In the second version, local governments purchase bike sharing services that are provided by others. In both cases, the revenue sources come from municipally funding.

On one hand, this model empowers local governments to have a bigger control over the system. On the other hand, local governments are 100% liable and they lack experience to provide such services compared to a specialized bike sharing operator.

In the **transport agency model**, transport operators that have previous knowledge and experience provide transport services of bike sharing services under the guidance of a public authority as an extension of other transport activities. Such companies obtain their revenue from government subsidiaries. As bike sharing became more popular, transport operators that in general move goods by ship, train, or truck (traditional business model) saw an opportunity to enter in urban mobility services. Usually, a transport agency operator needs to win a tender in order to be chosen for providing bike sharing services. Without a tender, these companies can be substituted by a more qualified operator (DeMaio, 2009).

The **university model** is the more small-scaled model due to fact that an educational institution provides the bike sharing service for its students. Although, this model enlarges the options for students to move around the campus and the city, this model would be left behind with another public bike sharing system that offers more bikes and dock stations.

In the **non-profit model**, companies provide bike sharing services under support of public councils or agencies in the form a public-private-partnership (Shaheen et al., 2010). The non-profit companies receive funds from providing the transit service as well as they collect revenue of the member's fees and sponsorship. Cities benefit from this model because the non-profit absorb the liability of the service, while on the other hand they rely on city council's funding (DeMaio, 2009).

Contrariwise, the **profit model** aims to provide economic profitable bike sharing services and distinguishes primarily from a minimal implication with the government. (Shaheen et al., 2010). This model lays out the freedom for the private sector to "start a service as an entrepreneurial activity rather than wait for the public sector to do so." (DeMaio, 2009)
The most popular bike sharing model is the **advertising company model** where companies like JCDecaux and Clear Channel Outdoor operate a bike sharing system in exchange for rights to display advertisements in different parts of the public space: on city street furniture, bus shelters, kiosks, billboards and even on bikes and stations of bike sharing. Since the revenue obtained from member fees and usage goes to local governments and not to advertising companies, these will have less incentives to improve the quality of the service.

2.2.4 IMPACTS OF BIKESHARING

Around bike sharing and active transportation, the literature that can be found is extensive. Thereupon, I will mention and explain the main theories about the various impacts and benefits bike sharing has and what a shift from combustion vehicles to active transportation can contribute to.
(Fishman, 2016) highlights in its paper that recent literature about bike sharing has some limitations in determining the impacts of bike sharing when it is a matter of interest to settle a standard methodology to enable an accurate and consistent measure of the several impacts bike sharing systems have on car use, congestion, climate change and public health.

The first positive impact of bike sharing refers to the direct health benefits of cycling (Andersen et al. 2000; Cavill and Davis 2006; Shepard 2008). In the same direction, DeMaio,2009 affirms that a modal shift from combustion transport to bike sharing creates a larger cycling population, decreases greenhouse emissions, and improves public health (DeMaio, 2009).

In addition, Shaheen et al., 2010 described some potential benefits of using bike sharing:

- Increased mobility options,
- Cost savings from modal shifts,
- Reduced traffic congestion,
- Reduced fuel use,
- Increased use of public transit and alternative modes,
- Increased health benefits,
- Greater environmental awareness.

Zhang & Mi, (2018) used big data techniques to calculate energy savings and emission reductions of bike sharing in Shanghai. They concluded that in one district with the highest environmental benefits for every square kilometre, bike sharing resulted in a reduction of 33 tonnes of petrol, 100 tonnes of CO_2, and 254 kg of NO_x in 2016. Nevertheless, these researchers did not include PM 2.5 in their calculations.

On the other hand, some academics estimated health impacts of a shift from car to active transport like walking and bicycling in general terms, without disaggregating data from bike sharing trips.

Rojas-Rueda et al., (2016) investigated the health impacts of promoting active modes of transport targeting people commuting populations between 16 and 64 years for 6 European cities including Barcelona. The researchers used similar health determinants as the study mentioned before:

- Changes in physical activity level,
- Exposure to fine particulate matter air pollution (PM 2.5)
- Traffic fatalities

The paper built various scenarios whereby the most probable was that in the short term, 35% of all trips were done by bicycle, again without differentiating bike sharing from traditional bikes. This investigation concluded that for every 100.000 travelers that shifted to bicycles, almost 38 deaths per year were postponed.
D. Rojas-Rueda et al., (2012) conducted a health impact assessment contrasting eight scenarios where long as short trips by car were replaced by a public transport mode or/and a bike. The primary outcome measure was all-cause mortality and change in life expectancy related to exposure of travelers to physical activity, PM 2.5 air pollution and road accidents. Although the impact on fine particulate matter was estimated, the research did not differentiate private bikes from Bicing.

Otero et al., (2018) also performed health impact assessment study to "quantify the health risk and benefits of car trips substitution by bikes trips from European BSS with > 2000 bikes". The researchers estimated three health determinants: physical activity, road traffic fatalities and air pollution of PM2.5. It is one of few papers that used data of fine particulate matter instead of C02 or other main pollutants.
The main conclusion was that "health benefits of physical activity outweighed the health risk of traffic fatalities and air pollution". Bicing was included in the study and with the actual level of car trip substitution they quantified an avoidance of 0,8 annuals deaths in Barcelona (95% CI). In the same way, they were able to quantify in monetary terms the saved or avoided cost shifting from car trips to bike sharing systems with the actual level of car trip substitution, for which Barcelona saved about 2,5 million € per year. Furthermore, they added different scenarios until a possible scenario where 100% of bike sharing trips came from cars (8,37 deaths avoided).

2.3 CONCLUSIONS OF THEORETICAL FRAMEWORK

Having analyzed the different related scientific literacy that cover bike sharing impacts, the conclusions are:

- PM 2.5 pollution will still rise despite the increasing adoption of electrical vehicles, because non-exhaust emissions will continue increasing, even though exhaust emissions have been reduced significantly.
- There is a lack of literacy about general bike sharing impacts in Spain compared to other developed countries.
- No study nor paper has tried to allocate the decreases of PM 2.5 pollution in Spain's most populated cities with the implementations of Bike sharing systems.
- No study nor paper has studied through the ***Fixed Effects Model*** the pollution levels of PM 2.5 before and after the implementation of BSS in Spain.

3 OBJECTIVES

Therefore, the objective of this bachelor thesis is to determine if all variations of PM 2.5 pollution of 12 cities in Spain can be explained through the result of BSS implementations or not, filling the gaps found in previous literature.

Thus, my hypothesis of investigation is the following one:

H_i = Bike sharing systems impact positively towards the reduction of PM 2.5 emission levels.

As mentioned in the theoretical framework, Spain has some room for improvement in terms of reducing PM 2.5 pollution, thus if the result of these study confirms that bike sharing reduces PM 2.5 particle emissions, further implementations of bike sharing systems in new cities would be more beneficial for their habitants.

4 DATA AND METHODOLOGY

In the current chapter I will explain the methodology and the data used to determine whether the implementations of bike sharing systems impact positively reducing PM 2.5 pollution. The study's aim is not to establish a positive relation between bike sharing systems implementations and PM 2.5 pollution, but to evidence that BSS reduces PM 2.5 emissions in 12 mid and large cities of Spain during 2008 and 2016.

In this context, the inhabitants of these 12 cities located in Spain can choose freely among different modes of transport: whether use private car, public transport like bus, metro, tram, or active transportation (walk and bicycle).

Citizens face a trade-off between travel time versus monetary cost. The individual demand for transport, the decision to choose between modes of transport, depends basically on various factors that can be resumed into:

- **Generalized cost of transport** comprised of transport monetary price and travel time. Both depend on the length of the trip, route, and time of the day. In addition, the higher the congestion levels in cities (like Barcelona and Madrid) the higher the generalized cost of transport.

- **Service quality of public transport** where punctuality and frequency play a key role.

- **Income** whereby people with a higher income will prefer to use private vehicle instead of public transport.

- **Price of other goods and services**

- **Tastes and preferences**

Having analyzed previous bike sharing related scientific literacy, I include in the analysis several variables that affect the PM2.5 concentration in a city as controls, jointly with my policy of interest variable. The included variables are the following:

- **BSS:** Variable that indicates whether the city under study has implemented a bike sharing system (BSS).
- **Population (pop):** Total number of habitants for each city including its urban agglomeration which by definition is a continuous urban spread constituting a town and its adjoining outgrowths.
- **GDP per capita (€)**: Common indicator used to measure the economic output per person of a country or a region, calculated by dividing its GDP by its population. It indicates the average socioeconomic status for each city.
- **Annual precipitation (l/m2):** Variable indicating the annual total amount of precipitation in liter per square meter for a location in average.
- **Annual average temperature (°C):** Average temperature of the maxima and minima for the warmest and coldest months of a year.
- **Metro / Tram:** Variable showing if the cities under study have access to the public transportation systems metro and tram.

The data of these variables have been extracted from different kind of sources.
The data of PM 2.5 pollution relies on the method outlined in van Donkelaar et al. (2019), which focus on the European subset that provides estimates between 33 and 80 degrees North and -15 and 45 degrees East, at 0.1 x 0.1 degree resolution (about 10 km x 10 km).

The variable **BSS** has been obtained through The Meddin Bike-sharing World Map, a data base in form of a map that Paul DeMaio, one of the top worldwide researchers about bike sharing systems, initiated in 2007 and since 2009 is curated by Russell Meddin.

The data about **Population** for every of the 12 cities has been obtained through a database in INE in the section “Cifras oficiales de población resultantes de la revisión del Padrón” published on the 30th of December of 2020.

The indicator **GDP per capita** has been downloaded from the publication “Contabilidad Regional de España. Revisión Estadística 2019 (SEC 2010)” published on the 17th of December of 2020, which is accessible in Spain’s official database, Instituto Nacional de Estadística (INE). This data accounts for the province of the city not for the concrete city, because such data was not available in INE and no official data could be found.

Nevertheless, the cities used in this study are all capitals of its provinces and concentrate most of the economic activity as well as population.

The source of information for **Annual Precipitation (mm/m^2)** as well as for **Annual average temperature (°C)** has been obtained from AEMET, Spain's Meteorological Agency. In the case of the annual average temperature, I had problems finding weather stations for some city centers, due to fact that AEMET and no other governmental database had available data within the city. Thus for the cities Bilbao, Córdoba, Málaga, Sevilla and Zaragoza I picked the weather stations located in their airports. In the case of Palma de Mallorca, it's average annual temperatures values come from its maritime port.

The variable of **metro/tram** has been created based on the data published in May 2019 in one of top Spain's economic newspapers "Expansion" were the years of launch of metros and trams are resumed. This variable relies as well as on data from the "Number of subway passengers in Spain in 2019, by city", a table published in Statista by Teresa Romero on Jan 13, 2021.

In order to test the hypothesis mentioned in Objectives (Section 3) of the current bachelor thesis, I will use the ***Fixed Effects Model,*** one type of Panel Data analysis. Thus, having in mind the variables of analysis mentioned earlier, I estimate the following equation that will determine that PM 2.5 emission levels have sunk because of the implementations of BSS for city *i* at year *t*:

$$\boldsymbol{PM\,2.5_{it} = \alpha + \beta_1 pop_{it} + \beta_2 GDPpc_{it} + \beta_3 BSS_{it} + \beta_4 metro_{it} +}$$
$$\boldsymbol{\beta_5 annualprecip_{it} + \beta_6 annu.avg.temp_{it}} + \sigma i + \lambda t + \varepsilon_{\text{it}}$$

where $\boldsymbol{PM\,2.5_{it}}$ is the natural logarithm of the concentration of fine particulate matter for city i in year t; $\boldsymbol{pop_{it}}$ is the population of city i in year *t*; $\boldsymbol{metro_{it}}$ is a dummy variable that takes the value of 1 when city i has a metro and / or a tram in year *t* and 0 otherwise; $\boldsymbol{annualprecip_{it}}$ is the level of precipitations in mm/m^2 at city *i* at year *t;* $\boldsymbol{annu.avg.temp_{it}}$ is the average temperature in ºC at city *i* at year *t;* σi are the cities fixed effects; λt are time fixed effects; and ε_{it} is a time-varying error assumed to be independent distributed. The coefficient $\boldsymbol{\beta_3}$ is the one I want to identify in this analysis, because it measures the effect of having a Bike Sharing System in city *i* at year *t.* The dependent variable is expressed in logarithm, since it helps identifying the effect of the policy in percentage.

The linear regression model equation underlines that $\boldsymbol{PM\ 2.5_{it}}$ is the outcome variable for cities *i* at year *t* followed by endpoints variables that can be classified into:

Continuous variables:	**Dichotomous variables (Dummies):**
$population_{it}$; $GDP\ per\ capita_{it}$; $length\ of\ urban\ bus\ lines_{\boldsymbol{it}}$; $annual\ precipitation_{\boldsymbol{it}}$ and $annual\ average\ temperature_{\boldsymbol{it}}$	BSS_{it} $metro_{it}$

The dichotomous variables, also named dummies, are in this thesis discrete variables that only provide 2 options, "0" for non-existence of metro nor bike sharing systems, "1" for their existence in city *i* at year *t.*

Having explained the methodology, I will continue with further explanations about the panel data I have built. The 12 cities that are contemplated in this sample are capital of their provinces and have more than 300.000 inhabitants. Every city has been assigned an ID in alphabetical order from 1 to 12. In the table below, the cities comprised in the sample can be found listed with their public bike sharing system names and launch date.

Table 1. Cities from sample with name of BSS and launch date

ID city	City	Name of BSS	Launch date
1	Alicante	ALABICI	01/01/2010
2	Barcelona	Bicing	01/03/2007
3	Bilbao	Bilbon Bizi	01/04/2011
4	Córdoba	Eco-bici Ciclocity	01/06/2003
5	Madrid	BiciMAD	23/06/2014
6	Málaga	malagabici	01/01/2013
7	Murcia	MUyBICI	18/03/2015
8	Palma	BiciPalma	01/01/2011
9	Sevilla	Sevici	01/01/2007
10	Valencia	Valenbisi	01/01/2010
11	Valladolid	Vallabici	06/05/2013
12	Zaragoza	Bizi	01/05/2008

Source: Own elaboration based on The Meddin Bike-sharing World Map, DeMaio (2007)

Barcelona, Córdoba, and Sevilla are the only three cities from the sample that have bike sharing systems during all the analyzed period from 2008 to 2016. In contrast, cities of Alicante, Bilbao, Madrid, Murcia, Málaga, Palma, Valencia, Valladolid, and Zaragoza launched their BSS during the analyzed period. Among the 12 cities, Alicante stands out, because its city council decided to shut down the BSS, four years after being implemented, due to vandalism, thefts of bikes and an overall bad management from the local public authorities. Thus, Alicante's citizens could only benefit from the bike sharing system between 2010 and 2013. Thereupon, the geographical location of the cities under study with BSS can be easily identified on the map created below.

Map 1. Map of Spanish cities with BSS

Source: Own elaboration

5 RESULTS

5.1 DESCRIPTIVE STATISTICS

STATA is the statistical program used to calculate and present the results of this bachelor thesis, which is a great software tool to manage an appropriate and accurate panel data analysis. As commented before, the bachelor thesis uses a linear regression model, the Fixed-Effects Model (FEM), as it is in my interest to analyze the impact of the variables (population, GDP per capita, annual average temperature, annual precipitation, BSS, and metro) that vary over time towards whether BSS implementations in 12 Spanish cities diminish PM 2.5 pollution or not. The Fixed-Effects Model explores the relationship between predictor and outcome variables within an entity (cities). In this case the entities are the 12 Spanish cities from the sample. Each city has its own individual characteristics that may or may not influence the predictor variables. The Fixed-Effects Model removes the effect of those time-invariant characteristics so we can assess the net effect of the predictors on the outcome variable. The Stata command to run fixed effects is *xtreg*, but before using it, I need to make Stata handle panel data by using the command *xtset*:

```
. xtset id year
       panel variable:  id (strongly balanced)
        time variable:  year, 2008 to 2016
                delta:  1 unit
```

Source: Own elaboration, results obtained from Stata

In this case "id" stands for city and represents the entities or panels (i) and "year" represents the time variable (t) during 2008 and 2016. The note "*(strongly balanced)*" refers to the fact that all cities have data for all years, otherwise the data would be unbalanced. Table 2 shows the descriptive statistics for the continuous variables picturing number of observations, the mean and standard deviation. The recollected data shows that the mean of PM 2.5 pollution for the 12 Spanish cities is 11,6 µg/m3 with a standard deviation of 2,03 µg/m3, quite underneath the EU standards (25 µg/m3), but slightly above the WHO guideline (10 µg/m3). According to the sample, PM 2.5 pollution varies between the minimum value of 7,1 µg/m3 corresponding to the city of Valladolid in 2013 and the maximum value of 17,7 µg/m3 of Alicante in 2009.

Table 2. Descriptive statistics of continuos variables

Variable	Obs	Mean	Std. Dev.	Min	Max
pm25	108	11.60741	2.030317	7.1	17.7
pop	108	1136312	1533029	301876	5552050
gdppercapita	108	22411.31	4773.527	15355	32840
annualprec~n	108	536.5926	290.5302	152.6	1647.5
annualaver~p	108	17.36574	2.148393	12.2	20.4

Source: Own elaboration, results obtained from Stata

In contrast, Table 3 presents the mean for the two dichotomous variables. When analyzing the share of cities that or have not BSS in the timeframe of 2008 to 2016, almost 63,8% of the observations in the sample have bike sharing systems compared to 36% observation that do not possess a BSS. Similarly, to BSS, the variable **Metro/Tram** can be found 65,74% amid the total number of observations from the sample. Comparing both modes of transportation, we can conclude that the existence of subways among the 12 Spanish cities from the sample, is slightly bigger, almost 2%, than the presence of bike sharing systems. A possible explanation for this higher presence of metro against BSS can be its much higher capacity and a larger number of people that use the metro, as the first subway systems were launched at the end of the 19th century and that the first generation of bike sharing was launched afterwards in 1965 in Amsterdam.

Table 3. Descriptive statistics of discrete variables BSS and Metro

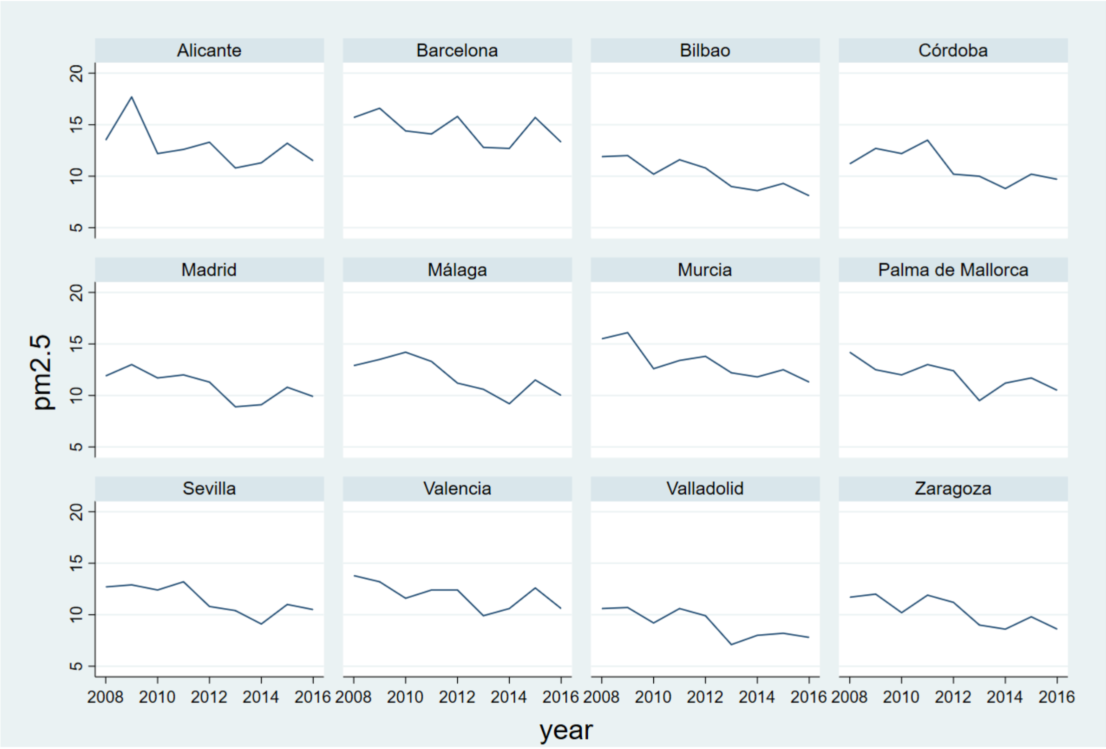
```
. tabstat bss metro
```

stats	bss	metro
mean	.6388889	.6574074

Source: Own elaboration, results obtained from Stata

Figure 10 is a Panel-data Matrix of line plots that displays the trend of PM 2.5 pollution in 12 Spanish cities with BSS. Analyzing the PM 2.5 emissions between 2008 and 2016, it can be concluded that every city has lowered its PM 2.5 emissions being all cities below the annual mean concentration of PM 2.5 at 25 µg/m3. Nevertheless, half of the cities have never had an annual mean during the same period below 10 µg/m3, as the WHO guideline recommends it for health reasons. Hence, policy makers in Spain need to keep improving in order to diminish still high PM 2.5 exposure around cities.

Figure 10. Trend of PM2.5 pollution in 12 Spanish cities with BSS



Source: Own elaboration, results obtained from Stata

5.2 AUTOCORRELATION

Serial correlation causes the standard errors of the coefficients to be smaller than they are. The **Wooldridge test**, a Lagram-Multiplier, allows to identify serial correlation using the command *xtserial*. As the result is 0.747, which is close to null, I can conclude that the data does not have first-order autocorrelation.

Table 4. Wooldridge test (Serial correlation)

```
Wooldridge test for autocorrelation in panel data
H0: no first order autocorrelation
    F(  1,       11) =       0.109
           Prob > F =       0.7469
```

Source: Own elaboration, results obtained from Stata

5.3 HETEROSCEDASTICITY

The **Breusch-Pagan and Cook-Weisberg test** is designed to detect any form of heteroskedasticity in a linear regression model. The first step is to do a regression analysis (command *regress*) with the 6 variables, four of which are continuous variables and 2 dichotomous (BSS and Metro). Analyzing the Anova table, the total variance is partitioned into the Model variance that can be explained by the independent variables and the Residual Variance, which cannot be explained by the independent variables. The term df stands for the degrees of freedom associated with the sources of variance. The total variance has N-1 degrees of freedom. In this case, there are N=108 observations, so the DF for total is 107. The model degrees of freedom correspond to the number of predictors minus 1 (K-1). The Residual degrees of freedom equal to 101, as it is calculated by subtracting DF total minus DF model.

The **F-value** is the Mean Square Model (37.5677631) divided by the Mean Square Residual (2.13532175), yielding F=17.59. The **P-value** associated with this F value is 0, so this concludes that the independent variables reliably predict the dependent variable PM 2.5 pollution. In other words, the independent variables show a statistically significant relationship with PM 2.5 pollution, the dependent variable.

Table 5. Breusch-Pagan and Cook-Weisberg test

```
. regress pm25 bss pop gdppercapita annualprecipitation annualaveragetemp metro

      Source |       SS           df       MS      Number of obs   =       108
-------------+----------------------------------   F(6, 101)       =     17.59
       Model |  225.406578         6  37.5677631   Prob > F        =    0.0000
    Residual |  215.667496       101  2.13532175   R-squared       =    0.5110
-------------+----------------------------------   Adj R-squared   =    0.4820
       Total |  441.074075       107  4.12218762   Root MSE        =    1.4613

------------------------------------------------------------------------------
        pm25 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         bss |  -1.746984    .316591    -5.52   0.000    -2.375015   -1.118952
         pop |   8.17e-07   1.16e-07     7.02   0.000     5.86e-07    1.05e-06
gdppercapita |  -.0000742   .0000566    -1.31   0.193    -.0001864     .000038
annualprec~n |   .0001402   .0005624     0.25   0.804    -.0009754    .0012558
annualaver~p |   .4292528   .0979244     4.38   0.000     .2349972    .6235085
       metro |   .0636166    .395416     0.16   0.873    -.7207825    .8480156
       _cons |   5.886737   2.563672     2.30   0.024     .8011009    10.97237
------------------------------------------------------------------------------

. estat hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of pm25

         chi2(1)      =     6.50
         Prob > chi2  =   0.0108
```

Source: Own elaboration, results obtained from Stata

Then we use the command *estat hettest* in Stata, which works off the null hypothesis that the variance for each observation has the same finite value, so that the observations are uniform. A large chi-square would indicate that heteroskedasticity was present. The following figure presents the results of the Breusch–Pagen test for heteroscedasticity, with a Chi-Square test statistic of 6.50. The p-value that corresponds to the Chi-Square test statist equals 0.01 and since this value is less than my significance value of 0.05, I reject the null hypothesis and conclude that heteroskedasticity is present in the data.

For this reason, I have created a new variable containing the natural logarithmic values of the continuous variables using the log function in Stata. Afterwards I re-ran the regression and heteroskedasticity test to see if transforming my dependent variable has any effect in the result. In comparison, the p-value of this test is 0.1539 and indicates no significance heteroskedasticity related to my independent variables.

Table 6. Breusch-Pagan and Cook-Weisberg test with logarithmic continuous variables

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of lpm25

         chi2(1)      =     2.03
         Prob > chi2  =   0.1539
```

Source: Own elaboration, results obtained from Stata

5.4 MULTICOLLINEARITY

The next step is to determine if the variables are correlated. Therefore, I use the command *correlate which* displays the correlation matrix for a group of variables. In the table below, the first pair of variables that show a significant negative correlation of -0.63 between GDP per capita and the annual average temperature. On contrast, Population and GDP present a positive correlation of 0.53.

Table 7. Multicollinearity of variables

```
. correlate bss pop gdppercapita annualprecipitation annualaveragetemp metro
(obs=108)
```

	bss	pop	gdpper~a	annual~n	annual~p	metro
bss	1.0000					
pop	0.1250	1.0000				
gdppercapita	-0.0701	0.5386	1.0000			
annualprec~n	-0.0348	0.0395	0.4386	1.0000		
annualaver~p	0.1115	-0.2532	-0.6347	-0.3213	1.0000	
metro	0.2697	0.3349	0.4212	0.1977	0.0687	1.0000

Source: Own elaboration, results obtained from Stata

As more than two predictors (variables) show a linear relationship, I need to detect if there is any multicollinearity, because as the degree of multicollinearity increases, the standard errors for the coefficients can get wildly inflated. Therefore, I use the *VIF* command, which stands for variance inflation factor. 1/VIF represents the tolerance and is widely used in the academic field to check on the degree of collinearity. Table 8 shows that the tolerance between GDP per capita and the annual average temperature and Population and GDP is equal to 1, which means there is no correlation between the independent variable and the other variables. If *VIF* exceeded 5 or 10, it would indicate a high multicollinearity between these two independent variables, but this is not the case.

Table 8 – VIF (Variance inflation factor)

```
. vif
```

Variable	VIF	1/VIF
gdppercapita	1.00	1.000000
Mean VIF	1.00	

```
. vif
```

Variable	VIF	1/VIF
annualaver~p	1.00	1.000000
Mean VIF	1.00	

Source: Own elaboration, results obtained from Stata

5.5 LINEAR REGRESSION WITH PANEL-CORRECTED STANDARD ERRORS (XTPCSE)

As mentioned before, I transpose the continuous variables into logarithmic, to be able to identify the outcome of the hypothesis of this Fixed Effects Method in an easier way, as the results will be presented in percentage. For this reason, I have proceeded with the calculation of the linear regression with panel-corrected standard errors. The command *xtpcse* was used to calculate it in Stata.

Table 9 – Linear regression with panel-corrected standard errors

```
. xtpcse lpm25 lpop lgdp lprec ltemp metro bss

Linear regression, correlated panels corrected standard errors (PCSEs)

Group variable:   id                          Number of obs      =       108
Time variable:    year                        Number of groups   =        12
Panels:           correlated (balanced)       Obs per group:
Autocorrelation:  no autocorrelation                         min =         9
                                                             avg =         9
                                                             max =         9
Estimated covariances      =        78        R-squared          =    0.4428
Estimated autocorrelations =         0        Wald chi2(6)       =    205.98
Estimated coefficients     =         7        Prob > chi2        =    0.0000
```

lpm25	Coef.	Panel-corrected Std. Err.	z	P>|z|	[95% Conf.	Interval]
lpop	.0874247	.0142536	6.13	0.000	.0594881	.1153613
lgdp	-.0506721	.1246532	-0.41	0.684	-.2949879	.1936437
lprec	-.0082795	.0308811	-0.27	0.789	-.0688053	.0522463
ltemp	.6248501	.1285212	4.86	0.000	.3729531	.8767471
metro	-.0023753	.0284598	-0.08	0.933	-.0581554	.0534048
bss	-.1410538	.0362247	-3.89	0.000	-.2120529	-.0700546
_cons	.1343552	1.3961	0.10	0.923	-2.60195	2.87066

6 CONCLUSIONS

In this section I will summarize and conclude the main results of my estimations. On the first hand, the Wooldridge test indicated a possible problem with autocorrelation and the Breusch–Pagan / Cook–Weisberg test showed an issue as well with heteroscedasticity. Despite that, doing further calculations on correlations and Variance inflation factors (VIF), autocorrelation and heteroscedasticity could not be found, so both were not problematic. The estimation results can be found in Table 10. Having done this Panel Data Analysis allows me to control for unobservable factors influencing PM 2.5 pollution the 12 Spanish cities. The coefficients for the 6 variables (Bike sharing systems, Population, GDP per capita, annual precipitation, annual average temperature, and metro) are reported in Table 10. The column “Pooled” provides the correlated panels corrected standard errors (PCSEs) and the column “Fixed Effects” procures the estimation of the Fixed-effects (within) regression.

The results show in both cases that the implementation of Bike sharing systems in the 12 Spanish cities have reduced the concentration of PM 2.5 pollution levels 14.10% and 15,50%, respectively. In addition, the fixed effects method determines that the variable temperature also has an impact towards PM 2.5 pollution, as the results show there is in important correlation. In just a period of 8 years, PM 2.5 emission levels have been reduced by 15.50% (Fixed-effects). If we look individually how the concentration of fine particulate matter has evolved from 2008 until 2016 (Table 11), all cities have reduced PM 2.5 µg/m3 pollution levels. Bilbao (-31.90%) has decreased PM 2.5 µg/m3 the most and the city of Córdoba the fewest with a contraction of only -13.40%.

After Bilbao, the cities that have diminished most are Murcia (-27.10%), Zaragoza (-26.50%), Valladolid (-26.40%), and Palma de Mallorca (-26.10%). Followed by Valencia (-23.20%), Málaga (22.50%), Sevilla (-17.30%), Madrid (-16.80%), Barcelona (-15.30%), Alicante (14.80%) and Córdoba (13.40%) as mentioned before. In average, every city contributed to a reduction of 1.29% of PM 2.5 microns per cubir meter air.

Table 10 – Estimation Results

VARIABLES	Pooled	Fixed effects
bss	**-0.141*** **	**-0.155*** **
	(-0.0362)	(-0.0333)
lpop	**0.0874*** **	0.0697
	(-0.0143)	(-0.732)
lgdp	-0.0507	**0.524***
	(-0.125)	(-0.262)
lprec	-0.00828	0.0499
	(-0.0309)	(-0.0519)
ltemp	**0.625*** **	**0.617*** **
	(-0.129)	(-0.117)
metro	-0.00238	-0.0483
	(-0.0285)	(-0.0349)
Constant	0.134	-5.667
	(-1.396)	(-10.12)
Year fixed effects	✓	✓
Urban area fixed effects	✗	✓
R-squared	0.443	0.364
Observations	108	108
Ids	12	12

Fixed effects estimation, clustered standard errors by id. Statistical significance at 1% (***), 5% (**) and 10% (*). Wooldridge test H0: no first—order autocorrelation; Breusch–Pagan/Cook–Weisberg test H0: constant variance. Pooled is the estimation with Linear regression, correlated panels corrected standard errors (PCSEs). Fixed effects is the estimation with Fixed-effects (within) regression.

The results presented here show the importance of BSS in urban areas to reduce still high and harmful concentrations of air pollutants like fine particulate matter in order to persevere lives and a cleaner and more sustainable environment.

This study can be for any public interest, but is more directed towards policy makers, local governments and even Bike sharing operators. This paper can contribute to reinforce the idea that Bike sharing systems need to become bigger and more efficient, with the purpose that more people use Bike sharing as an alternative mode of transportation. I recommend local government authorities to boost the usage of bike lanes and improve the public bike sharing system adding more capacity and increasing the share of electric bikes among stations. The idea of incorporating a common card that combines all public modes of transportation within a city: Bus, BSS and Metro among others would have a positive impact towards increasing the number of users.

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