Trends in Clean Air Legislation in Europe: Particulate Matter and Low Emission Zones[1]

Hendrik Wolff and Lisa Perry - University of Washington

May 1st, 2010

Abstract:

The European Union (EU) Clean Air Directive is currently among the strictest acts of legislation worldwide concerning PM10 air pollution. The most visible result of the new PM10 legislation has been the rapid adoption of "Low Emission Zones" (LEZs), which define areas that vehicles may enter only if they are classified as low PM10 emitting vehicles. High-polluting vehicles are not allowed to be driven into LEZs. This article describes recent developments in Europe concerning clean air legislation, focusing in particular on the legislation of particulate matter (PM). The article begins with a discussion of the health impacts of PM, and then traces the history of ambient PM standards in the EU. After comparing ambient PM standards in the EU with those in the United States, we discuss Germany's implementation of LEZs, including public reaction to the policy. We also provide a brief overview of other urban traffic-related policies aimed at reducing air pollution.

JEL classification: K32 (Environmental, Health, and Safety Law), Q53 (Environmental Economics, Air Pollution)

Keywords: European Union Clean Air Directive, Particulate Matter, Low Emission Zone

[1] We thank the Umweltbundesamt of Germany and the Kraftfahrtsbundesamt of Germany for helpful discussions concerning the vehicle emission categories and the details about particulate matter measurement problems. We are grateful for the research grant provided by the Royalty Research Fund of the University of Washington.

Introduction

The European Union (EU) Clean Air Directives[2] are currently among the strictest acts of legislation worldwide concerning PM10 air pollution.[3] It is an ambitious and comprehensive attempt to control this pollutant's negative health effects by mandating that every city within the EU's 27 member states measure PM10 on an hourly basis and enforce tight PM10 limits. Cities and communities face stiff financial penalties if they are not in compliance with the legislation. Nonetheless, many urban areas are currently in violation of the directive. Thus, many European cities and local governments have started to implement aggressive measures to reduce ambient PM10, mostly from vehicle emissions.

One of the most aggressive responses to the new PM10 legislation in Europe has been the rapid adoption of so called "Low Emission Zones" (LEZs). An LEZ defines an area that a vehicle is allowed to enter only if it is classified as a low PM10 emitting vehicle. All high polluting vehicles are banned from driving into the LEZ. To date, LEZs have been implemented in 152 cities in 9 EU countries. Germany, in particular, has been at the forefront of efforts worldwide to establish LEZs.

This article describes recent developments in Europe concerning clean air legislation, focusing in particular on the legislation of particulate matter (PM) and the implementation of LEZs as a response to stricter PM10 limits. The article begins with an overview of PM10 and its health impacts, and then traces the evolution of ambient PM standards in the EU from the 1980s until today. Next ambient PM standards in the EU are compared with those in the United States. This is followed by a discussion of the implementation of LEZs in Germany and public reaction to the policy. The final section offers some conclusions and a brief overview of alternative urban traffic-related policies that can be used to reduce air pollution from particulate matter.

---

[2] Directives are legislative acts of the EU where member states can choose the specific means of achieving the outcome. Directives are different from a "EU regulations", which are self-executing and do not require member states to pass additional implementing measures. The EU Clean Air Directives refer to a series of Directives, including 96/62/EC, 1999/30/EC and 2008/50/EC, which set air quality standards for all 27 EU member countries.

[3] Particulate matter—or PM—refers to the sum of all solid or liquid particles suspended in the air. PM10 refers to particulate matter that has a diameter of 10 micrometers or less. Similarly, PM2.5 refers to all PM that is smaller than 2.5 micrometers in diameter.

Particulate Matter and Health Concerns

Particulate matter (PM) is a complex mixture consisting of small solid fragments, fragments with solid cores and liquid exteriors, and liquid fragments. These fragments consist of various materials, such as metal, soot, soil, dust, or a combination of these materials. The two most regulated classes of particulates are PM10 and PM2.5. The 10 and 2.5 refer to the size of the particles, measured as the diameter of the particle in micrometers (µm).[4] The level of PM10 or PM2.5 in the atmosphere is measured as the quantity of PM10 or PM2.5 particles in micrograms per cubic meter, $\mu g/m^3$.

PM is created as a direct result of burning fuels such as oil, gasoline, or wood. However, windblown dust as well as chemical reactions between sulfur dioxide (SO_2), nitrogen oxides (NOx) and other substances (e.g., ammonia) can indirectly contribute to atmospheric levels of PM. Diesel emissions are especially harmful, since diesel particles are generally smaller (and hence can enter the lungs more easily) and because their composition is especially damaging to health. In most European urban areas road transport-related emissions are the primary source of ambient PM10 (Krzyzanowski, 2005). Road transport is also largely responsible for most emissions of NO_X, carbon monoxide (CO) and benzene in European urban areas (Krzyzanowski, 2005). While these other toxins are also addressed under the EU Clean Air Directive, threshold violations and health impacts are substantially higher for PM10. Thus the legislation of these other air pollutants is not discussed here.

PM10 has been linked to serious cardiopulmonary diseases, acute respiratory infection, and trachea, bronchus and lung cancers (EPA, 2004). The adverse effects are most prevalent among the elderly, the very young, and those with existing ailments such as asthma and acute and chronic bronchitis. Worldwide, about 6.4 million years of healthy life are lost due to long-term exposure to ambient PM10 (Cohen et al., 2005). In the EU alone, PM10 is estimated to cause 348,000 premature deaths annually. In comparison, ozone—the second most deadly air pollutant among EU countries—causes only about 21,000 premature deaths annually (Watkiss et al., 2005). The European Commission (EC)[5] has taken these health impacts very seriously, and, in response, enacted the 2005 Clean Air Directive, which marks an unprecedented attempt to mandate low levels of PM10.

---

[4] In comparison, an average human hair has a diameter of 60 µm.
[5] The EC is the executive body of the EU. It proposes implements and enforces EU legislation.

The Evolution of Particulate Matter Legislation in Europe

In the EU, those aspects of environmental legislation that directly affect human health are standardized in a system of laws that apply to all EU member states. The EC in Brussels passes directives that set standards with respect to ambient air quality. As a response each member state must implement their own policies to attain these standards and have to report these to the EU. (In case of non-compliance to adequately report or obtain the EU standards, member states risk financial penalties by the EU court system). When the first serious PM legislation was approved in the 1980s, the EU consisted of only nine member states, all Western European countries. Today, however, EU legislations directly affect almost 500 million people in 27 EU member states, including many Eastern European countries.

Early Particulate Matter Policy

The early regulation of particulate matter occurred during a time when the world was concerned more about the detrimental effects of acid rain and forest decline due to SO_2 emissions than the health effects of PM10. In this context the EU passed the Council Directive of July 15th, 1980 (80/779/EEC), which set air quality limits for SO_2 and suspended particulates. Total suspended particulates include all particles suspended in the air, while PM10 includes only those particulates that are smaller than 10 μm.[6]

Council Directive 80/779/EEC went into effect on April 1, 1983, and applied to all 10 EU member states (Greece had joined the EU in 1981). The directive requires that concentrations of SO_2 and suspended particulates in member countries comply simultaneously with the legislation (see Table A in Annex I of the Directive, as amended in 89/427/EEC). Interestingly, in 1980 individual thresholds were established only for suspended particulates, as measured by the "black smoke" method.[7] These thresholds were set higher for the winter months (October 1 to March 31) than for the rest of the year.[8] More specifically, the limit for the median of the daily

[6] While the different measurement methods used across EU countries make it difficult, if not impossible, to define a common conversion factor, Schikowski et al. (2005) have estimated that PM10 accounts for about 71% of the total suspended particulate concentrations in the Ruhr area of Germany.

[7] The "black smoke" method is a way of measuring suspended particles by analyzing a stain left on paper filters exposed to the air in question. See Annex II of the Directive 89/427/EEC for details.

[8] Due to temperature inversions and increased heating requirements, PM10 levels are often higher in the winter than in the summer (Klinger and Sahn, 2008).

mean value was 80 μg/m^3 for April through September and 130 μg/m^3 during the winter months. The directive also included details on the methods to be used for measuring the air pollutants and mandated that air pollution measurement stations be located at sites where pollution was thought to be greatest and where the measured concentrations were representative of local conditions (Article 6 of 80/779/EEC). Furthermore, member states were required to inform the European Commission of cases in which the air pollutant thresholds had been exceeded. Many of the elements contained in this early legislation concerning suspended particulate matter were also included in the stricter, more recent legislation on particulate matter, which is described below.

The EU's 2005 Particulate Matter Policy

In response to increased concerns about the detrimental health effects of air pollution, the EU has issued a series of Clean Air Directives which introduced EU-wide limits on ambient PM10. First, 1996 Council Directive 96/62/EC, commonly referred to as the Air Quality Framework Directive, establishes the general legal framework for regulating air pollution. The directive describes the basic technical principles for assessing and measuring air quality and how individual member states should translate the framework into national law. Importantly, the directive lists all the pollutants for which air quality standards and objectives must be further developed through amendments, the so-called "daughter directives".

The first daughter directive, Council Directive 1999/30/EC, spells out specific numerical limits on ambient levels of SO_2, NO_x, PM and lead. While this directive addresses both PM10 and PM2.5, it establishes numerical limits only for PM10. This directive initially divided the PM10 limits into two phases, with the first phase covering 2005 to 2009 and the second stage covering 2010 and beyond (see Table 1). During the first stage, PM10 is regulated such that at a city's highest-polluting station

(a) the daily average does not exceed 50 μg/m^3 on more than 35 days annually and

(b) the yearly average does not exceed 40 μg/m^3.

These thresholds are applied to a calendar year,[9] and became effective on January 1, 2005. Given the historical distribution of daily and average PM10 concentrations, it was clear from the beginning that the daily limit (a) would be harder for cities to attain than the annual limit (b)

---

[9] This differs from the earlier directive of 1980, which established different thresholds for the summer and winter season.

(Brunekreef and Maynard, 2008). Stedman et al. (2007) estimate that the daily limit is approximately equivalent to an annual average limit between 30 and 33 µg/m³.

To provide an indication of just how strict these 2005 PM10 limits are, as of 2007, 70 percent of all EU cities with populations greater than 250,000 had violated the limits at some point, and, as of 2006, all EU member countries except Ireland and Luxembourg had cities that were in violation of the PM10 threshold (Europa Press Release, 2008).

Table 1: European Union PM10 pollution thresholds of Directive 1999/30/EC

	Phase 1 starting January 1, 2005	Phase 2 starting January 1 2010
Yearly average limit	40 µg/m³	20 µg/m³
Daily average (24-hour) limit	50 µg/m³	50 µg/m³
Allowable exceedance days per year	35	7

The EU's Planned 2010 Particulate Matter Policy

The second phase of the EU's PM10 policy (1999/30/EC) planned to impose stricter limits on cities and local governments. Starting on January 1, 2010, the PM10 thresholds were to change such that at a city's highest-polluting station

(a) the daily average does not exceed 50 µg/m³ on more than *seven* days annually and

(b) the yearly average does not exceed 20 µg/m³.

These tighter standards would have been very difficult for many European cities; for instance, the German data we present below imply that over three times as many cities are at risk of non-attainment. As a response to these predicted difficulties, in 2008 the EU abolished the second phase of the announced 2010 PM10 limits, and instead replaced it by a new PM2.5 legislation which will be described next.[10]

The EU's PM2.5 Policy

[10] In particular, in 2008, the EC passed Council Directive 2008/50/EC, which among others, reinforced the 2005 limits, abolished the expected 2010 PM10 limits and introduced new PM2.5 limits, as well as demanded a stricter legislation concerning measurement, reporting and non-compliance and penalty issues. While the expectation of the 2010 limits were still very important in motivating cities to reduce PM10 (and were particularly important for Germany in motivating the LEZ regulation), there is currently no indication of whether these stricter 2010 limits will be put into effect again in the future.

Thus far, we have focused primarily on the EU's legislation concerning PM10. However, epidemiological research indicates that the finer the particles the greater the health damages, since fine and ultra fine particles can enter deep into the lungs and partially into the bloodstream. With this in mind, Council Directive 1999/30/EC (the first "daughter directive") also required basic PM2.5 monitoring, mandating that member states report daily concentrations of PM2.5 to the European Commission. However, as noted above, the directive did not set threshold levels or penalties for PM2.5, and the determination of the number and exact locations of PM2.5 measuring stations was left up to each member state.

Ten years later, Council Directive 2008/50/EC, on Ambient Air Quality and Cleaner Air for Europe, established PM2.5 thresholds for the first time[11]:

(a) By 2020 member states must reduce their PM2.5 Average Exposure Indicator–or AEI--by up to 20%, based on their 2010 levels. The AEI is calculated as the three-calendar year running annual mean concentration averaged across targeted urban areas.[12]

(b) The PM2.5 AEI of these targeted urban areas is set at 20 $\mu g/m^3$, to be met by 2015.

(c) The annual average PM2.5 level cannot exceed 25 $\mu g/m^3$ in any targeted or non-targeted area by 2015.

(d) In 2020, the annual average PM2.5 limit will be tightened to 20 $\mu g/m^3$, to be met by any measuring station (for both the targeted areas and non-targeted areas).

The EU notes that threshold (d) is an indicative limit value to be reviewed by the Commission in 2013 in light of additional updated information on health effects and technical feasibility (Council Directive 08/50/EC).

In comparison to the EU PM10 standards, none of the EU PM2.5 standards are very stringent. Brunekreef and Maynard (2008) argue that the 25 $\mu g/m^3$ annual limit (c) is stricter than the national averages (a) and (b), which are based on AEI, since these latter measures are averaged over 'clean' and 'dirty' cities. Even the 25 $\mu g/m^3$ annual limit (c) is not that strict,

[11] According to the European Commission, there is not yet an identifiable limit below which PM2.5 would not be considered harmful. Given this ambiguity, the regulation of PM2.5 aims at a general reduction of concentrations (Council Directive 08/50/EC).

[12] Thus, the AEI for 2010 would be based on the average across 2008, 2009 and 2010. Countries with an AEI less than 8.5 $\mu g/m^3$ are exempt from this general reduction. Targeted urban areas are defined as having certain PM2.5 assessment values in prior years, as outlined in Annex II.A.2 of 2008/50/EC).

however, as many urban areas in Europe are already below that limit and 25 μg/m³ is at the upper end of epidemiological exposure-response curves (Brunekreef and Maynard, 2008). Moreover, ratios of PM2.5 to PM10 across Europe are around 0.6-0.7 (Querol et al., 2004). This means that the 25 μg/m³ annual PM2.5 limit corresponds to an annual PM10 limit of 36 to 42 μg/m³. Given that the daily limit on PM10 corresponds to a 30 to 33 μg/m³ annual limit (Stedman et al., 2007), it appears that for most European countries the PM10 limit is likely to be more binding than the PM2.5 limit (Brunekreef and Maynard, 2008).

Enforcement and Penalties

In the first few years of the Clean Air Directive, responsibility for implementing measures to achieve the air quality levels mandated by the EU was left solely to member states. Moreover, supervision and enforcement of the directive, as well as the design of penalties, were also left to individual member states.

However, over time, the EU Commission found this decentralized method to be unsatisfactory. Meeting the standards for PM10 has proven to be a challenge for member states. In fact, twenty-three of the twenty-seven member states, including Germany, reported exceeding the PM10 limits in 2005, the first year that the standard was in effect (European Press Release, 2007).[13]

As a result of this low compliance, in 2008 the European Commission passed Directive 2008/50/EC, which initiated more stringent supervision and enforcement of the standards, including penalties for non-compliance. Since violations of the standards were so common, and countries presented different explanations for why they could not meet the PM10 limits (e.g., unusual weather patterns, measurement problems), the 2008 Directive does allow a number of exceedances of the limits, as long as it can be demonstrated convincingly that such exceedances occurred because of unusual circumstances, such as temporary road sanding, construction sites close to the measurement unit, winter road salting, or unusual wind patterns from neighboring districts with high levels of particulate matter. Sweden and the Netherlands, for example, have been successful in using the exception clause for winter road sanding. The directive also includes procedures for applying for extensions to meet the standards. In order to receive an extension from the Commission, a member state must prove that it has made a strong attempt to meet the

[13] Luxembourg has failed to provide any report and an infringement case has been opened in response.

targets and must have a detailed strategy for meeting future air quality targets.[14] In addition, new Eastern European member states are given additional time to meet the EU standard. However, no exceptions are granted for reporting PM10 levels.

If the Commission finds an application for extension to be unconvincing, the application may be denied. If the country subsequently fails to comply after receiving two warning letters from the Commission, the Commission can call for an infringement proceeding at the European Court of Justice (ECJ) in Luxemburg. In fact, in January 2009, the Commission initiated infringement proceedings against 10 EU countries that have not attained the PM10 limit: Cyprus, Estonia, Germany, Italy, Poland, Portugal, Slovenia, Spain, Sweden and the UK. Such proceedings can result in substantial financial penalties (European Press Release, 2009a, 2009b).

The financial penalties are calculated according to a detailed formula.[15] The basic formula is:

$$\textit{Daily penalty} = (\textit{Flat Rate} * \textit{Seriousness} * \textit{Duration})\ N$$

That is, the daily penalty to be paid by a violating city is the product of: 1) the basic flat penalty rate, which is currently set at 600 Euros for all offenses; 2) the coefficient of seriousness, which is based primarily on the severity of the violation's impacts on human health and the ecosystem; 3) the coefficient of duration, which is based on the duration of the non-compliance and the responsiveness of the government that is in violation; and 4) a country factor *N*, which is based on both the ability of the violating country to pay (determined by the country's GDP) and its number of votes in the EC.[16] Because the penalty formula is multiplicative, the fines can quickly

---

[14] However, the deadline for compliance cannot be extended beyond June 11, 2011 (European Press Release, 2008; 2008/50/EC).

[15] For details on this formula, see Article 228 of the European Treaty (EC Treaty 228).

[16] The *N* factor is a geometric mean calculated by taking the square root of the product of a normalized member state's GDP and its votes in the Council, such that

$$N = \sqrt{\frac{GDP_n}{GDP_{Lux}} * \frac{Votes_n}{Votes_{Lux}}}$$

GDP_n = GDP of the member state concerned, in millions of Euros, GDP_{Lux} = GDP of Luxembourg, $Votes_n$ = number of votes each Member State has in the Council under the weighting laid down in Article 205 of the Treaty and $Votes_{Lux}$ = number of votes of Luxembourg. The choice of Luxembourg as a reference country has no influence on reach high levels. For example, the German city of Leipzig faces a potential penalty of 700,000 Euros per day (US$1,050,000 per day) because the ambient PM10 level measured in the city center has repeatedly exceeded the PM10 limits. To avoid this penalty, the city is currently working on an improved action plan and aims to quickly adopt an LEZ.

Under European law, citizens of EU member countries have recently become entitled to demand that local authorities rapidly develop action plans to address air pollution. This is due to an important ruling by the ECJ in July 2008 concerning a case brought by a Munich resident who claimed that the EU Air Quality Directive required the city of Munich to take action to stop pollution from exceeding the specified target. In response to the ruling, Munich implemented an LEZ in October of 2008 (European Court of Justice, 2008).

Comparison of EU and U.S. Particulate Matter Policies

To help put the EU's PM10 limits in perspective, this section briefly describes the history of PM limits in the United States and compares U.S. PM regulations to the EU's policies. PM10 regulation was mandated much earlier in the United States than in the EU. In 1987, at a time when Europe was still monitoring only total suspended particulates, the United States undertook a major revision of the Environmental Protection Agency (EPA) health- and welfare-based standards for PM10. Beginning in 1987, the U.S. PM10 limits were:

(1) a 24-hour standard set at 150 $\mu g/m^3$, and

(2) an annual average standard set at 50 $\mu g/m^3$.

To determine if a location was in compliance with the annual standard, PM10 data were collected daily and averaged over the entire year. The annual averages for the previous three years were then used to determine attainment status. Furthermore, a location met the 24-hour standard only if it exceeded 150 $\mu g/m^3$ no more than one day per calendar year.

The annual 24-hour standard for PM10 was lifted in 1997, but a new PM2.5 standard was introduced by the EPA, which set the annual average at 15.0 $\mu g/m^3$ and the 24-hour standard at 65 $\mu g/m^3$. The 24-hour limit is violated if the 3-year average of the annual 98th percentile

---

the relative level of the parameters for any two given countries. The factor *N* varies in the European Union between 0.36 for Malta and 25.4 for Germany. Due to the multiplication of multiple coefficients the fines can quickly reach high levels, in particular for high *N* countries such as Italy (*N* = 19.84), The UK (21.99), Germany (25.4) and France (21.83).

concentrations is greater than the 65 μg/m^3 limit. This is equivalent to requiring that the daily average not exceed 65 μg/m^3 more than seven days per year. Hence, by 1997, the U.S. had implemented a PM2.5 standard that was more stringent than the EU standard.

Moreover, in 2006 the U.S. tightened the 24-hour PM2.5 standard by almost 50 percent, to 35 μg/m^3. This new 24-hour limit and the annual average limit of 15.0 μg/m^3 are still in effect. The 24-hour standard binds[?] more often than the annual standard, with about twice as many counties violating both the 24-hour and annual standards as those violating only the annual standard (Brunekreef and Maynard, 2008).

While it is often difficult to compare how stringent limits are, given differences in factors such as monitoring station location and how PM10 is measured, the EU PM10 limit values are tighter than in the U.S. but the U.S. PM2.5 limits are tighter compared to the EU PM2.5 limits. In terms of PM10, while the U.S. only has an annual average limit of 50 μg/m^3, the EU has an annual limit of 40 μg/m^3 and the more binding 24-hour limit of 50 μg/m^3, not to be exceeded on more than 35 days in a calendar year. In comparison, the annual U.S. PM2.5 limit of 15 μg/m^3 is clearly lower than the current EU limit of 25.0 μg/m^3. Even in 2020, when the EU's annual PM2.5 limit will be 20 μg/m^3, the EU PM2.5 legislation will still not be as low as the current U.S. limit. One has to be cautious however, with the direct comparisons of the limits between two jurisdictions, as many other factors are different as well. For example, the EU legislation is more stringent in that the limit values refer to one year averages, whereas the U.S. limits apply to three-year averages. Also there exist differences in the exact location of the PM measurement station, as in which distance and altitude these have to be located from a major road. Finally, the various legislations allow for exception rules. So for example the EU 2008 Directive does allow a number of exceedances of the limits, as long as it can be demonstrated convincingly that such exceedances occurred because of "unusual circumstances", such as temporary road sanding, construction sites close to the measurement unit, winter road salting, or unusual wind patterns from neighboring districts with high levels of particulate matter.

California has gone beyond the U.S. federal standards with its adoption of the Ambient Air Quality Standards (AAQS) for particulate matter, resulting in one of the most stringent PM regulations worldwide. According to the California Environmental Protection Agency's Air Resources Board, California standards are required to be set such that the maximum amount of particles present in outdoor air does not threaten the public's health[17]. To this end, in June 2002, the Air Resource Board adopted new, revised PM standards for outdoor air, lowering the annual PM10 limit from 30 μg/m^3 to 20 μg/m^3 and establishing a new annual standard for PM2.5 in California of 12 μg/m^3, which is just 3 μg/m^3 below the federal annual standard (California Air Resources Board, 2002). California's 24-hour average of 50 μg/m^3 applies to the highest daily average over a three-year period (see Table 2). While the California PM10 annual limits would have been on par with EU second stage 2010 limits, both California's annual and 24-hour standard are more stringent than the current 2005 EU PM10 standards. Given that California's PM2.5 is more stringent than the U.S. one, it would also follow that it is more stringent than the EU PM2.5 limit.

Table 2: Current California and U.S. Federal Air Quality Standards for Particulate Matter

	California Standard PM10	Federal EPA Standard PM10
Annual Average	20 μg/m3	N/A
24-Hour Average	50 μg/m3	150 μg/m3
	California Standard PM2.5	Federal EPA Standard PM2.5
Annual Average	12 μg/m3	15.0 μg/m3
24-Hour Average	--------	35 μg/m3

Low Emission Zones in Germany

Particulate Matter in Germany

Like most of Europe, Germany has struggled to meet the EU PM10 limits, especially the daily limit. Between 2005 and 2007, 79 German cities violated the 35-day limit (i.e., their daily average PM concentrations exceeded 50 μg/m^3 on more than 35 days in each year) while only 12 of these cities also violated the 40 μg/m^3 annual limit.

Moreover, as shown in Table 3, almost all of Germany was at risk of being in non-attainment of the announced 2010 standards. Based on historical emissions levels from 2005 to

[17] See California Health & Safety Code section 39606

2008, Wolff and Perry (2010) estimated that 285 German cities would have violated the 2010 limits. In fact, in each year since 2005, even the German national average PM10 level would have violated the 2010 annual average limit as well as the exceedance days limit.

Table 3: Germany violations of PM10 limits

	2005	2006	2007	2008
National average PM10 [µg/m³]	24.4 (5.2)	26.2 (5.5)	23.1 (5.3)	21.2 (4.9)
Mean number of days** above 50 µg/m³	19.6 (20.9)	26.8 (21.1)	16.2 (15.8)	11.6 (12.9)
Cities in violation of 2005 standard	36	65	31	18
Cities that would have violated 2010 standard	226	246	200	134

*The calculation of the expected number of cities violating the 2010 standard is based on the number of cities that would have violated the standard between 2005 and 2008 either because of exceedance days or high annual averages
**: Average of the highest exceeding station per city; Standard deviations in parentheses
Source: Wolff and Perry, 2010

To deal with the large number of cities exceeding the PM10 threshold, the German government requires that any German city with an air pollution station in non-attainment immediately develop a clean air action plan (AP). If the AP is not developed or is considered by the EU to be unsatisfactory, then the EU can impose significant financial penalties.

Thirty to fifty percent of measured PM10 and NOx emissions in Germany come from transportation sources (Friedrich, 2008). Given the high concentrations of traffic-based PM10 in Germany's urban areas, the country's APs have been aimed at reducing these emissions through the following measures:[18]

(a) expanding public transportation

(b) utilizing ring roads

(c) improving traffic flow

(d) implementing LEZs

Number and Size of LEZs

[18] While these measures target PM10 in specific urban areas in Germany, there are also national and EU regulations on tailpipe emissions, fuel efficiency and gasoline content that target air pollution more generally. These other measures are described briefly in Appendix A.

Implementation of LEZs has emerged as the most common, yet most aggressive and controversial, feature of Germany's clean air action plans. As of January 2010, 41 German cities had implemented LEZs. The remaining cities that have violated the PM10 standard have developed APs that include measures (a) to (c). However, almost all of these cities are also considering implementing an LEZ, and in fact many have LEZs planned for the near future.

LEZs mostly cover city centers, but vary considerably in size. The largest LEZ, in Stuttgart, covers an area of 207 km^2 with 590,000 inhabitants, while a smaller LEZ in nearby Illsfeld covers only 2.5 km^2 with 4,000 inhabitants.[19]

Vehicle Classes

To implement the LEZ policy, the German government has categorized all vehicles (46 million cars and trucks) into four classes based on EU-wide tailpipe PM10 emissions categories (Federal Law Gazette, 2002 and Federal Ministry of Justice, 2007). The four classes correspond to Europe-wide emission standards Euro 1 through Euro 4[20]. These standards are based on vehicle features such as size, weight, type of engine (e.g., diesel, gasoline, natural gas, electric), horsepower, intended use (e.g., vacation home, truck, bus), number of seats, model year, and combined emissions of PM10 and other tailpipe pollutants (NOx, CO and total hydrocarbons (THC))[21].

Each German vehicle—as well as each visiting foreigner—that seeks to enter a LEZ must display a colored windshield sticker indicating its PM10 pollution class. Vehicle entry into LEZs is restricted based on the color of the sticker, with some cities permitting only the cleanest vehicles (green stickers), and others allowing more pollution classes (yellow and red) into their LEZs. There are four PM10 classes for diesel vehicles, which account for 29 percent of German vehicles currently on the road (Wolff and Perry 2010). The highest emitting diesel vehicles

---

[19] A map of the current and planned LEZ in Germany is displayed in English under the following link: http://www.umwelt-plakette.de/umweltplakette/Karten%20Umweltzonen%20D/UZ-BRD-GR-oCC-eng.pdf

[20] See Appendix A for more details on the Euro classes

[21] Although the levels of these other tailpipe pollutants help determine the PM10 class of the vehicle, the four PM10 classes were designed specifically for the PM10 and LEZ regulation in Germany. Thus, the vehicle sticker is referred to as the "Feinstaubplakette", or "PM10 sticker/badge". For more detail concerning the four PM10 vehicle classes, see 35. BImSchV, appendix 2 in German Federal Ministry of Justice (2007).

cannot obtain any sticker (and hence cannot enter any LEZ), while red, yellow, and green stickers are given to progressively 'cleaner' vehicles, as shown in Table 3. There are only two pollutant classes for gasoline-powered vehicles, green stickers for clean vehicles and no sticker for vehicles that are too dirty to enter any LEZ.

Some vehicles can be retrofitted to obtain a "cleaner" sticker, with conversion to the next class costing approximately US$800 to US$2500 for smaller vehicles and US$7,000 to US$22,000 dollars for larger vehicles and trucks. However, conversion is technologically infeasible for some vehicles.

Table 3: German vehicle stickers

	Sticker categories			
	No sticker	Red	Yellow	Green
Requirement for diesel vehicles	Euro 1 or worse	Euro 2 or Euro 1 with particle filter	Euro 3 or Euro 2 with particle filter	Euro 4 or Euro 3 with particle figure
Requirement for gasoline vehicles	Without 3-way catalytic converter			Euro 1 with regulated catalytic converter or better

See the appendix for further information on the Euro classes 1 to 4.

Implementation and Penalties

The implementation date and the types of cars restricted by LEZs vary across German cities. In Berlin, for example, starting in January 2008 all vehicles with a red sticker or "cleaner" (i.e., yellow or green) were allowed into the LEZ, while starting on January 1, 2010 access was restricted to only those vehicles with green stickers. However, the LEZ on Dortmund'sBrackler Street has permitted only yellow and green sticker cars since January 2008.

The fine for illegally entering an LEZ is 40 Euros plus one penalty point on the driver's license. There is a series of consequences for penalty points, ending with loss of the driver's license at 18 points. There are exceptions that allow certain emergency and other work-related vehicles to enter LEZs without a sticker, including agricultural and forestry tractors; ambulances and doctors' cars; vehicles driven by or carrying persons with serious mobility impairments; and police, fire brigades, German and NATO military vehicles.

Impacts and Public Response

The LEZ policy has been very controversial in Germany because millions of commercial trucks and privately owned vehicles can no longer enter areas that have now been designated as LEZs. The LEZ policy also has potentially far-reaching consequences for the large numbers of people living within the LEZs (e.g., 1.1 million people live inside the Berlin LEZ alone). LEZs can also impose high costs on businesses located inside LEZs and on commercial truck or bus companies that had previously driven into towns that now have LEZs. Business owners often complain that LEZs lead to declining sales (especially from foreign visitors who often do not buy a windshield sticker). In Freiburg, a city which is often visited by neighboring French and Swiss tourists, for example, it is estimated that the LEZ has caused a decline in revenue of about 100 million Euros per year. One business owner referred to the LEZ as the "*biggest imbecile of all times*" (Badische Zeitung, 2009).

Whether the LEZs are an effective method to reduce PM10 is still an open question and much debated in the popular press. In fact, according to a recent online survey, over 91% of Germans reject LEZs as being too bureaucratic and likely having little effect (DSM, 2009). In an earlier survey, 70% of drivers stated that they hesitated to drive into a LEZ (Vienken, 2008), which likely contributes to higher PM10 levels in areas outside of the LEZ. Major newspapers have published articles on the LEZ policy with headlines such as "*Particulate Matter: The insanity of LEZs*" (Bild, 2009), "*Will the LEZ become a Revenue Killer*" (Badische Zeitung, 2009), "*Driving Ban in LEZs: Much Dust for Nothing*" (Süddeutsche, 2009), "*Fight against a phantom*" (FAZ, 2008).

Despite these criticisms, LEZs have become a popular program used by local governments in Germany to meet the EU limits. In fact, anticipating the threat of the stricter 2010 standards, all larger German cities are currently adopting even more restrictive LEZs in order to meet the new. By 2012 over 50 percent of all LEZs in Germany will allow only yellow sticker and cleaner vehicles, and by 2013 the large majority of all cities with LEZs will allow only green sticker vehicles (Climate Company, 2009).

Conclusions and Alternative Policies

The European Union has been regulating particulate matter since the 1980s. Today, the EU has among the strictest limits on PM10 worldwide. . As European cities and local governments face high penalties for non-compliance with these limits, and are struggling to find effective measures to reduce PM10 and PM2.5. The most aggressive and widespread measure has been the establishment of LEZs. However, LEZs are not the only policy instrument that can reduce urban air pollution.

Another policy instrument that has been established worldwide is the License Plate Program (LPP), which became popular in Mexico and has since been established in Bogota (1998), Santiago (1986), São Paolo (1997), San Jose (2005), La Paz (2003), all of Honduras (2008), and most recently in Beijing (2008). LPP typically prohibits driving one weekday per week based on the last digit of the license plate. LEZs might have an advantage over LPPs in that they can target the dirtiest vehicles and may circumvent some of the unintended consequences of LPPs, as described in Davis 2008 (e.g. purchasing an even dirtier second car instead of upgrading the first car).

Other forms of driving restrictions to reduce air pollution include partial and total bans (Italy, Athens, Amsterdam, Barcelona, and Tokyo); traffic cell architecture, which allows vehicles to be driven within the cell but drivers must take a circumferential ring road to get between traffic cells (Goddard 1997; Vuchic 1999); traffic bans on days when air pollution exceeds certain thresholds (Milan and other Northern Italian cities); and congestion pricing in combination with an LEZ.

The main competitors to the LEZ program are policy instruments that establish more direct price incentives. Price-based policies that aim to limit congestion and emissions include road pricing and congestion fees. Air pollution policies that provide direct price incentives to the driver have been implemented in Milan, London, Singapore and Tokyo. Singapore (1975), London (2003) and Stockholm (2006) all charge fees for driving into the city center. For example, London requires each driver to pay a congestion charge of 8 British Pounds per day of driving in the city center. Due to the stricter EU legislations and environmental concerns, London recently also established an LEZ whereby those cars that have low emissions are exempt from the eight pound congestion charge. While New York City's congestion fee plans stalled in the legislature, San Francisco is currently debating a six dollar fee to drive through downtown. Milan has combined congestion pricing and LEZs with its Ecopass program, which charges fees to drive downtown based on the car’s emissions level. Despite the increasing adoption of such price-based policies, command and control driving restrictions are more often adopted because these policies are easier to implement politically, are technologically more feasible, and are relatively less expensive to enforce (Levinson and Shetty, 1992; Davis, 2008).

In the future, as more epidemiological related studies are able to distinguish between the health effects of PM10 versus PM2.5 or even PM1.0, policies may move in the direction of imposing more specific limits on these finer pollutants. Currently the United States, especially California, is at the forefront of PM2.5 regulation, while the EU is the strictest world-wide in terms of PM10.[22] Meeting these standards require innovative measures to reduce urban air pollution. However, whether LEZs, LPPs, road pricing, or some combination of policies is the most effective way to meet strict PM standards is still an open question, and further analysis of these and other measures and policies is clearly needed.

References

An, F. and A. Sauer (2004), Comparison of Passenger Vehicle Fuel Economy and Greenhouse Gas Emission Standards around the World, The Pew Center on Global Climate Change, Washington, DC.

Auffhammer, Maximilian and Ryan Kellogg. 2009. Clearing the Air? The Effects of Gasoline Content Regulation on Air Quality. CSEM Workig Paper 185 (submitted).

Badische Zeitung (2009): Wird die Feinstaubplakette zum Umsatzkiller?

Bild (2009): Feinstaub: Der Irrsinn mit den Umweltzonen. Article of the Bild Zeitung, published November 24th, 2009. Accessed online on Bild.de on November 24, 2009.

Brunekreef, Bert and Robert Maynard (2008). “A note on the 2008 EU standards for particulate matter.” Atmospheric Environment 42, 6425–6430.

California Air Resources Board (2002): Resolution 02-24, June 20, 2002. http://www.arb.ca.gov/regact/aaqspm/res0224.pdf.

Climate Company (2009): GEMB Gesellschaft für Emissionsmanagement und Beratung mbH, Geschäftsführer Michael Kroehnert, HRB 101917 AG Berlin Charlottenburg. Available on the internet at http://www.umwelt-plakette.de/

Cohen AJ, Ross Anderson H, Ostro B, et al. (2005): The global burden of disease due to outdoor air pollution. J Toxicol Environ Health A, 68: 1301–7.

[22] As noted in the discussion of U.S. regulations, California’s ambient PM10 standards are approximately equal to those in the EU.

Council Directive (1980): Council Directive 80/779/EEC of 15 July 1980 on air quality limit values and guide values for sulphur dioxide and suspended particulates. Official Journal. No L 229, 30. 8. p. 30.

Council Directive 08/50/EC (2008). Journal of the European Communities L 152, pp. 1–44.

Council Directive 96/62/EC (1996). Journal of the European Communities 296, 21.11. p. 55–63.

Council Directive 99/30/EC (1999). Official Journal of the European Communities, L 163/60.

Davis, Lucas (2008). “The Effect of Driving Restrictions on Air Quality in Mexico City.” Journal of Political Economy 116(1): 38-81.

Dockery, Douglas, et al. (1993). "An Association Between Air Pollution And Mortality In Six US Cities." New England Journal of Medicine 329(1993): 1753–1759.

DSM Online Survey (2009): Online Survey of Deutschlands schnellste Meinung. Accessed online at http://www.bild.de/BILD/dsm/deutschlands-schnellste-meinung.html on November 24, 2009.

EC Treaty 228: Communication from the Commission: Application of Article 228 of the EC Treaty, SEC(2005) 1658.

EPA (2004): Air Quality Criteria for Particulate Matter (Final Report, Oct 2004). U.S. Environmental Protection Agency, Washington, DC, EPA 600/P-99/002aF-bF..

Europa Press Release (2007): "Air pollution: Commission takes action over levels of sulphur dioxide and PM10 in member states". Brussels, P/07/1537, October 17, 2007.

Europa Press Release (2008): Environment: Commission requests information from Member States on PM10 pollution, IP/08/1112.

Europa Press Release (2009a): Time Extensions for PM10, Nitrogen Dioxide and Benzene. http://ec.europa.eu/environment/air/quality/legislation/time_extensions.htm

Europa Press Release (2009b): Air pollution: Commission starts legal action against 10 Member States over airborne particles , IP/09/174. http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/174

European Court of Justice (2008): Judgment of the European Court of Justice in Case C-237/07, Press Release No 58/08, 25 July 2008. Dieter Janecek v Freistaat Bayern

FAZ (2008): Neue Umweltzonen: Kampf gegen ein Phantom. Article in FAZ from January 3rd, 2008. Accessed online at FAZ.de on November 24, 2009.

German Federal Ministry of Justice (2007): Fünfunddreißigste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung zur Kennzeichnung der Kraftfahrzeuge mit geringem Beitrag zur Schadstoffbelastung -35. BimSchV. Document created October 10th, 2006. Last date document was changed: May 12th, 2007.

Federal Law Gazette: 22nd Ordinance for the Implementation of the Federal Immission Control Act (Ordinance on Immissions of Airborne Pollutants – 22. BImSchV), of 11 September 2002, Federal Law Gazette I 2002, p. 3626.

Friedrich, Alex (2006): Barriers and Bottlenecks to implementing Integration. Umweltbundesamt (UBA), Germany. Paper presented at "Transport, Health, Environment, Institutional Arrangements for Policy Integration", Berlin 2006.

Klinger, Matthias and Elke Sahn (2008). "Prediction of PM10 Concentration on the Basis of High Resolution Weather Forecasting." Meteorologische Zeitschrift 17(3): 263-272.

Krzyzanowski, Michal (2005). "Health Effects of Travel-Related Air Pollution: Summary for Policy Makers." World Health Organization ISBN 92-890-1375-3.

Levinson, Arik and Sudhir Shetty (1992). "Efficient Environmental Regulation: Case Studies of Urban Air Pollution in Los Angeles, Mexico City, Cubatao and Ankara." Policy Research Working Paper no. 942, World Bank, Washington, D.C..

Querol, X., Alastuey, A., Ruiz, C.R., Artinano, B., Hansson, H.C., Harrison, R. M., Buringh, E., ten Brink, H.M., Lutz, M., Bruckmann, P., Straehl, P., Schneider, J., 2004. Speciation and origin of PM10 and PM2.5 in selected European cities. Atmos. Environ. 38, 6547–6555

Schikowski et al. (2005). "Long-term air pollution exposure and living close to busy roads are associated with COPD in women." Respiratory Research 2005, 6:152.

Stedman, J.R., Kent, A.J., Grice, S., Bush, T.J., Derwent, R.G., 2007. A consistent method for modelling PM10 and PM2.5 concentrations across the United Kingdom in 2004 for air quality assessment. Atmos. Environ. 41, 162–171.

Süddeutsche (2009): Fahrverbot in Umweltzonen: Viel Staub um Nichts. Article of the Süddeutsche Zeitung, published November 24th, 2009. Accessed online on sueddeutsche.de on November 24, 2009.

Timilsina, H.R and G.B B. Dulal (2009). "A Review of Regulatory Instruments to Control Environmental Externalities from the Transport Sector." World Bank Policy Research Working Paper 4867.

Vienken (2008): Summary of Survey about LEZ: Deutsche Autofahrer zweifeln am Sinn und Zweck von Umweltzonen: Knapp 70% wuerden nach Moeglichkeit Umweltzonen umfahren. Survey by DA Direkt Versicherung. Accessed online at www.presseportal.de/pm/17575/1165262/da_direkt_versicherung on November 24, 2009.

Vuchic, Vukan R. (1999). Transportation for Livable Cities, CUPR Press.

Watkiss, P. S. Pye S, Mike Holland (2005). CAFE CBA: baseline analysis 2000 to 2020. Report to the European Commission DG Environment, Brussels.

Wolff, H. and L. Perry (2010): Evaluation of Low Emission Zones in Europe, mimeo, University of Washington.

Appendix A: Fuel Efficiency, Tailpipe Emissions, Fuel Content Regulations

Meeting air quality standards through LEZs is not the only way that governments can reduce air pollution. The EU and U.S. have both also set standards that target vehicle fuel efficiency, tailpipe emissions, and fuel content. Through increased fuel efficiency, vehicles use less fuel per mile and therefore lower the associated emissions per mile. Tailpipe emissions standards, on the other hand, limit the emissions in vehicle exhaust, thereby reducing emissions per gallon of fuel used. In both the EU and U.S., fuel efficiency and tailpipe standards are applicable only to new vehicles. Conversely, fuel standards, which regulate the amounts of polluting substances like sulfur and lead that can be in fuel, affect how much of these substances are emitted by all vehicles. This appendix briefly outlines efficiency, tailpipe and fuel content regulations in the EU and also provides some references to the U.S.

Comparing fuel efficiency standards across countries is not simple given the differences in testing and measurement. Some regulations take the form of numeric standards based on vehicle fuel consumption (e.g., liters of gasoline per hundred kilometers or miles per gallon), while other regulations target green house gas (GHG) emissions, which while not directly regulating fuel use, often affect fuel use (An and Sauer 2004). The U.S. has used Corporate Average Fuel Economy (CAFE) Standards since 1975 to set sales-weighted fuel-efficiency standards, which are now separate for passenger cars and light trucks. In the EU, a voluntary agreement between the EC and European Automobile Manufacturers Association (ACEA) in 1998 sets targets for reductions in carbon dioxide emissions. In 1999, these agreements were also ratified by the Japanese and Korean manufacturers (JAMA and KAMA) that sell in Europe. An and Sauer (2004) convert the EU GHG emissions standards to an equivalent CAFE standard and find that the EU (and Japan) have the strictest standards worldwide. Neither the 2007 U.S. Energy Independence and Security Act, which will increase CAFE standards to 35 miles per gallon, nor California's GHG emission standards are as stringent as the EU standards.

The U.S. introduced tailpipe emissions standards for CO, volatile organic compounds (VOC) and NOx through the Clean Air Act of 1970. These standards have been increasingly tightened since then, with limits on particulates and hydrocarbons also being added. California has adopted its own stricter tailpipe emission standards. While the United Nations Economic Commission for Europe (UN-ECE) had historically set EU-wide vehicle emission standards, the EU adopted EU Directive 94/12/EC in 1994 to tighten vehicle tailpipe emissions (Timilsina and

Dulal, 2009). These standards, which set limits on CO, hydrocarbons (HC) HC+NOx, NOx and PM, establish six stages (Euro 1 to Euro 6, with Euro 6 taking effect in September of 2014 and beyond) of progressively tighter standards, with separate standards for diesel- and gasoline-powered vehicles. The standards also depend on vehicle features.

The Euro classes are described in further detail in the 1970 directive (70/220/EEC) and its amendments (91/441/EEC, 93/59/EEC, 94/12/EC, 96/69/EC, 2002/51/EC (row A), 2006/120/EC, 98/69/EC[14], 2002/51/EC (row B), 2006/120/EC, 98/69/EC, 2002/80/EC, and 2007/715/EC). In general the larger the vehicle the higher the PM10 limits of the Euro classes. The Euro 1 to Euro 4 classes are also used to define the four PM10 emission categories and whether vehicles obtain the red, orange or green windshield sticker or no sticker.

Fuel content standards are also important in reducing vehicle-based pollution, since cleaner fuel will decrease emissions from new and existing vehicles. For example, the U.S. banned leaded gasoline in 1995 and reached an agreement with the Alliance of Auto Manufacturers to reduce sulfur content in gasoline to "near-zero" levels (less than 5 mg/kg) by 2007.[23] The EU has taken similar steps, banning leaded gasoline in 2000 and requiring that gasoline and diesel fuels contain a maximum of 10 mg/kg sulfur by January 2009 (Timilsina and Dulal, 2009). Both the EU and the United States have also taken steps to reduce the sulfur dioxide content of diesel used in heavy vehicles. While both allowed 500 mg/kg of sulfur in diesel in 1996, this has now been reduced to 15 mg/kg in the U.S. and 10 mg/kg in the EU (Timilsina and Dulal, 2009).

[23] See Auffhammer and Kellogg (2009) for a recent summary on the U.S. fuel content regulations.