

Trends in Clean Air Legislation in Europe: Particulate Matter and Low Emission Zones¹

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Introduction

The European Union (EU) Clean Air Directive² is 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 twenty-seven 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 directive's requirements. 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 PM₁₀ legislation in Europe has been the rapid adoption of the 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 nine 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 particulate matter (PM) and the implementation of LEZs as a

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²Directives are legislative acts of the EU that allow member states to choose the specific means for achieving the required outcome or objective. In contrast, EU "regulations" are self-executing (i.e., they supersede national legislation) and thus do not require member states to pass additional implementing measures. The EU Clean Air Directive refers to a series of directives, including 1996/62/EC, 1999/30/EC, and 2008/50/EC, which set air quality standards for all 27 EU member countries.

³Particulate 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, PM_{2.5} refers to all PM that is smaller than 2.5 micrometers in diameter.

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 PM.

PM and Health Concerns

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 PM_{2.5}. 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 PM_{2.5} in the atmosphere is measured as the quantity of PM₁₀ or PM_{2.5} particles in micrograms per cubic meter, $\mu\text{g}/\text{m}^3$.

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 (NO_x), 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, while ozone—the second most deadly air pollutant among EU countries—causes only about 21,000 premature deaths annually (Watkiss, Pye, and Holland 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.

The Evolution of PM 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

⁴In comparison, an average human hair has a diameter of 60 μm .

⁵The EC is the executive body of the EU. It proposes, implements, and enforces EU legislation.

directives that set standards with respect to ambient air quality. In response, each member state is required to implement its own policies to attain these standards and report them to the EU.⁶ 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 legislation directly affects almost 500 million people in twenty-seven EU member states, including many Eastern European countries.

Early PM Policy

The early regulation of PM occurred during a time when the world was more concerned about the detrimental effects of acid rain and forest decline due to SO₂ emissions than the health effects of PM₁₀. In this context, the EU passed the Council Directive of July 15, 1980 (80/779/EEC), which set air quality limits for SO₂ 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 .⁷

Council Directive 80/779/EEC, which went into effect on April 1, 1983, applied to all ten EU member states (Greece had joined the EU in 1981) and required that member countries comply simultaneously with the limits on concentrations of SO₂ and suspended particulates (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.⁸ These thresholds were set higher for the winter months (October 1 to March 31) than for the rest of the year.⁹ More specifically, the limit for the median of the daily mean value was 80 $\mu\text{g}/\text{m}^3$ for April through September and 130 $\mu\text{g}/\text{m}^3$ 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 EC of cases in which the air pollutant thresholds had been exceeded. Many of the elements contained in this early legislation concerning suspended PM were also included in the stricter, more recent legislation on PM, which is described below.

The EU's 2005 PM 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 introduces EU-wide limits on ambient PM₁₀. The first, Council Directive 1996/62/EC, commonly referred to as the Air Quality Framework Directive, was issued in 1996 and establishes the general legal framework for regulating air

⁶If a member state fails to adequately attain or report on the EU standards, it risks financial penalties, which are imposed through the EU court system.

⁷While 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.

⁸The “black smoke” method measures suspended particles by analyzing a stain left on paper filters exposed to the air in question. See Annex II of Directive 89/427/EEC for details.

⁹Due to temperature inversions and increased heating requirements, PM₁₀ levels are often higher in the winter than in the summer (Klinger and Sahn 2008).

Table 1 European Union PM10 pollution thresholds

	Phase 1 Starting January 1, 2005	Phase 2 Starting January 1, 2010
Yearly average limit	40 $\mu\text{g}/\text{m}^3$	20 $\mu\text{g}/\text{m}^3$
Daily average (24-hour) limit	50 $\mu\text{g}/\text{m}^3$	50 $\mu\text{g}/\text{m}^3$
Allowable exceedance days per year	35	7

Source: Council Directive 1999/30/EC.

pollution. It 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 divided the PM10 limits into two phases, with the first phase covering 2005–2009 and the second phase covering 2010 and beyond (see table 1). During the first phase, PM10 is regulated such that, at a city’s highest-polluting station,

- (1) the daily average does not exceed 50 $\mu\text{g}/\text{m}^3$ on more than 35 days annually; and
- (2) the yearly average does not exceed 40 $\mu\text{g}/\text{m}^3$.

These thresholds are applied to a calendar year,¹⁰ 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 (1) would be more binding (i.e., harder for cities to attain) than the annual limit (2) (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 $\mu\text{g}/\text{m}^3$.

To provide an indication of just how strict the first phase (2005–2009) 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).

The EU’s Planned 2010 PM Policy

Under Council Directive 1999/30/EC, the second phase of the EU’s PM10 policy was supposed to impose even 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,

- (1) the daily average does not exceed 50 $\mu\text{g}/\text{m}^3$ on more than 7 days annually; and
- (2) the yearly average does not exceed 20 $\mu\text{g}/\text{m}^3$.

¹⁰This differs from the earlier directive of 1980, which established different thresholds for the summer and winter seasons.

These tighter standards would have been very difficult for many European cities to meet. For instance, as discussed below, almost all of Germany was at risk of nonattainment of the 2010 limits. In response, in 2008 the EU passed Council Directive 2008/50/EC, on Ambient Air Quality and Cleaner Air for Europe, which abolished the second phase of the PM10 policy and introduced new PM2.5 legislation (discussed below). This directive also maintained the 2005 PM10 limits beyond 2009¹¹ and demanded stricter legislation concerning measurement, reporting, and noncompliance and penalty issues.

The EU's PM2.5 Policy

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) required basic PM2.5 monitoring, mandating that member states report daily concentrations of PM2.5 to the EC. 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 (the same directive that abolished the 2010 PM10 limits) established PM2.5 thresholds for the first time:¹²

- (1) By 2020, member states must reduce their PM2.5 Average Exposure Indicator—or AEI—by up to 20 percent, based on their 2010 levels. The AEI is calculated as the three-calendar-year running annual mean concentration averaged across targeted urban areas.¹³
- (2) The PM2.5 AEI of these targeted urban areas is set at $20 \mu\text{g}/\text{m}^3$, to be met by 2015.
- (3) The annual average PM2.5 level cannot exceed $25 \mu\text{g}/\text{m}^3$ in any targeted or non-targeted area by 2015.
- (4) In 2020, the annual average PM2.5 limit will be tightened to $20 \mu\text{g}/\text{m}^3$, to be met by any measuring station (for both the targeted areas and nontargeted areas).

The directive notes that threshold (4) 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.

In comparison to the EU PM10 standards, the EU PM2.5 standards are not very stringent. Brunekreef and Maynard (2008) argue that the $25 \mu\text{g}/\text{m}^3$ annual limit (3) is stricter than the national averages (1) and (2), which are based on AEI, since these latter measures are

¹¹While the expectation of the stricter 2010 limits motivated cities to reduce PM10 (and was particularly important in motivating Germany's LEZ policy), there is currently no indication as to whether the 2010 limits will be implemented in the future.

¹²According to the EC, there is not yet an identifiable limit below which PM2.5 would not be considered harmful. Given this ambiguity, the PM2.5 legislation seeks a general reduction of concentrations (Council Directive 2008/50/EC).

¹³Thus, the AEI for 2010 would be based on the average across 2008, 2009, and 2010. Countries with an AEI less than $8.5 \mu\text{g}/\text{m}^3$ 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).

averaged over “clean” and “dirty” cities. Even the $25 \mu\text{g}/\text{m}^3$ annual limit (3) is not that strict, however, as many urban areas in Europe are already below that limit and $25 \mu\text{g}/\text{m}^3$ is at the upper end of epidemiological exposure-response curves (Brunekreef and Maynard 2008). Moreover, ratios of PM_{2.5} to PM₁₀ across Europe are around 0.6–0.7 (Querol et al. 2004). This means that the $25 \mu\text{g}/\text{m}^3$ annual PM_{2.5} limit corresponds to an annual PM₁₀ limit of 36–42 $\mu\text{g}/\text{m}^3$. Given that the daily limit on PM₁₀ corresponds to a 30–33 $\mu\text{g}/\text{m}^3$ annual limit (Stedman et al. 2007), it appears that for most European countries the PM₁₀ limit is likely to be more binding than the PM_{2.5} 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 2005 standards for PM₁₀ has proven to be a challenge for member states. In fact, twenty-three of the twenty-seven member states reported exceeding the PM₁₀ limits in 2005, the first year that the standard was in effect (Europa Press Release 2007).¹⁴

Because of this low compliance, Council Directive 2008/50/EC also included more stringent supervision and enforcement of the 2005 PM₁₀ standards, including penalties for noncompliance. 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 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 PM. 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 PM₁₀ standards. In order to receive an extension, a member state must prove that it has made a strong attempt to meet the targets and must have a detailed strategy for meeting air quality targets in the future.¹⁵ 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 EC 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 Luxembourg. In fact, in January 2009, the Commission initiated infringement proceedings against ten EU countries that have not attained the 2005 PM₁₀ limit: Cyprus, Estonia, Germany, Italy, Poland, Portugal, Slovenia, Spain, Sweden, and the

¹⁴Luxembourg has failed to provide any report and an infringement case has been opened in response.

¹⁵However, the deadline for compliance cannot be extended beyond June 11, 2011 (European Press Release, 2008; 2008/50/EC).

United Kingdom. Such proceedings can result in substantial financial penalties (Europa Press Release 2009a, 2009b).

The financial penalties are calculated according to a detailed formula.¹⁶ The basic formula is:

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

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 noncompliance 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.¹⁷ The value of the N factor ranges from 0.36 for Malta to 25.4 for Germany. Because the penalty formula is multiplicative, the fines can quickly reach high levels, particularly for cities in high N countries such as Italy ($N = 19.84$), the United Kingdom (21.99), Germany (25.4), and France (21.83). For example, the German city of Leipzig faces a potential penalty of 700,000 Euros per day (U.S. \$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 (2008/50/EC) 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. PM 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

¹⁶For details on this formula, see Article 228 of the European Treaty (EC Treaty 228).

¹⁷The N factor is a geometric mean calculated by taking the square root of the product of a member state's normalized GDP and its votes in the Council, such that

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

where 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 the relative level of the parameters for any two given countries.

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 $150 \mu\text{g}/\text{m}^3$; and
- (2) an annual average standard set at $50 \mu\text{g}/\text{m}^3$.

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 3 years were then used to determine attainment status. Furthermore, a location met the 24-hour standard only if it exceeded $150 \mu\text{g}/\text{m}^3$ no more than 1 day per calendar year.

The annual 24-hour standard for PM₁₀ was lifted in 1997, but a new PM_{2.5} standard was introduced by the EPA, which set the annual average at $15.0 \mu\text{g}/\text{m}^3$ and the 24-hour standard at $65 \mu\text{g}/\text{m}^3$. The 24-hour limit is violated if the 3-year average of the annual 98th percentile concentrations is greater than the $65 \mu\text{g}/\text{m}^3$ limit. This is equivalent to requiring that the daily average not exceed $65 \mu\text{g}/\text{m}^3$ more than 7 days per year. Hence, by 1997, the United States had implemented a PM_{2.5} standard that was more stringent than the EU standard.

Moreover, in 2006, the United States tightened the 24-hour PM_{2.5} standard by almost 50 percent, to $35 \mu\text{g}/\text{m}^3$. This new 24-hour limit and the annual average limit of $15.0 \mu\text{g}/\text{m}^3$ are still in effect. The 24-hour standard binds more often than the annual standard, with about twice as many countries violating both the 24-hour and annual standards as those violating only the annual standard (Brunekreef and Maynard 2008).

While differences in factors such as monitoring station location and how PM₁₀ is measured often make it difficult to compare the stringency of limits, the EU PM₁₀ limit values are tighter than those in the United States but the PM_{2.5} limit values in the United States are tighter than those in the EU. In terms of PM₁₀, the annual average limit in the United States is only $50 \mu\text{g}/\text{m}^3$, while the EU has an annual limit of $40 \mu\text{g}/\text{m}^3$ and the more binding 24-hour limit of $50 \mu\text{g}/\text{m}^3$, not to be exceeded on more than 35 days in a calendar year. In comparison, the annual U.S. PM_{2.5} limit of $15 \mu\text{g}/\text{m}^3$ is clearly lower than the current EU limit of $25.0 \mu\text{g}/\text{m}^3$. Even in 2020, when the EU's annual PM_{2.5} limit will be $20 \mu\text{g}/\text{m}^3$, it will still not be as low (i.e., strict) as the current U.S. limit. One has to be cautious, however, with direct comparisons as there are other differences between jurisdictions. For example, the EU limit values refer to 1-year averages, whereas the U.S. limits apply to 3-year averages, making the EU legislation more stringent. There are also differences in the exact locations of PM measurement stations, such as distance from a major road and altitude. Finally, the EU legislation allows certain exceptions, whereas the United States does not.

California has gone beyond the U.S. federal standards with its adoption of the Ambient Air Quality Standards (AAQS) for PM, resulting in one of the most stringent PM regulations worldwide. According to the California EPA'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.¹⁸ To this end, in June 2002, the Air Resource Board adopted new, revised PM standards for outdoor air, lowering the annual PM₁₀ limit from $30 \mu\text{g}/\text{m}^3$ to $20 \mu\text{g}/\text{m}^3$ and establishing a new annual standard for PM_{2.5} in California of $12 \mu\text{g}/\text{m}^3$, which is just $3 \mu\text{g}/\text{m}^3$ below the federal annual standard (California Air Resources Board 2002).

¹⁸See California Health & Safety Code section 39606.

Table 2 Current California and U.S. federal air quality standards for particulate matter

	California standard PM10	Federal EPA standard PM10
Annual average	20 $\mu\text{g}/\text{m}^3$	N/A
24-hour average	50 $\mu\text{g}/\text{m}^3$	150 $\mu\text{g}/\text{m}^3$
	California standard PM2.5	Federal EPA standard PM2.5
Annual average	12 $\mu\text{g}/\text{m}^3$	15.0 $\mu\text{g}/\text{m}^3$
24-hour average	—	$\mu\text{g}/\text{m}^3$

Sources: California Air Resources Board 2002; EPA 2006.

Table 3 Germany violations of PM10 limits

	2005	2006	2007	2008
National average PM10 [$\mu\text{g}/\text{m}^3$]	24.4 (5.2)	26.2 (5.5)	23.1 (5.3)	21.2 (4.9)
Mean number of days* above 50 $\mu\text{g}/\text{m}^3$	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

Note: Standard deviations in parentheses.

*Average of the highest exceeding station per city.

**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.

Source: Wolff and Perry 2010.

California's 24-hour average of 50 $\mu\text{g}/\text{m}^3$ applies to the highest daily average over a 3-year period (see table 2). While the California PM10 annual limits would have been on a par with the second phase (2010) of the EU's limits, California's annual and 24-hour standards are both more stringent than the current (2005) EU PM10 standards. Since California's PM2.5 limit is more stringent than the U.S. federal standard, it would also follow that California's limit is more stringent than the EU's PM2.5 limit.

PM and LEZs in Germany

Like most of Europe, Germany has struggled to meet the EU PM10 limits, especially the daily limit. Between 2005 and 2007, seventy-nine German cities violated the 35-day limit (i.e., their daily average PM concentrations exceeded 50 $\mu\text{g}/\text{m}^3$ on more than 35 days in each year), of which twelve also violated the 40 $\mu\text{g}/\text{m}^3$ annual limit. Moreover, as shown in table 3, almost all of Germany was at risk of being in nonattainment of the planned 2010 standards. Based on historical emissions levels from 2005 to 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.

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 nonattainment 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 50 percent of measured PM10 and NOx emissions in Germany come from transportation sources (Friedrich 2006). 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:¹⁹

- (1) expanding public transportation
- (2) utilizing ring roads
- (3) improving traffic flow
- (4) implementing LEZs

Implementation of LEZs has emerged as the most common, aggressive, and controversial feature of Germany's clean air APs. As of January 2010, forty-one German cities had implemented LEZs. The remaining cities in violation of the PM10 standard have developed APs that include measures (1) to (3). 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 km² with 590,000 inhabitants, while a smaller LEZ in nearby Illsfield covers only 2.5 km² with 4,000 inhabitants.²⁰

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 German Federal Ministry of Justice 2007). The four emissions classes correspond to the Europe-wide emissions standards, Euro 1 through Euro 4, which establish progressively tighter standards for vehicle emissions.²¹ 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]).²²

Each German vehicle—as well as each visiting foreigner—that seeks to enter an LEZ must obtain and 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 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

¹⁹While 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.

²⁰For a map of the current and planned LEZs in Germany (in English), see <http://www.umweltplakette.de/umweltplakette/Karten%20Umweltzonen%20D/UZ-BRD-GR-oCC-eng.pdf>.

²¹See Appendix A for more details on the Euro classes.

²²Although 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).

Table 4 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 filter
Requirement for gasoline vehicles	Without three-way catalytic converter			Euro 1 with regulated catalytic converter or better

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

Source: Climate Company 2009.

table 4. 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 U.S. \$800–2500 for smaller vehicles and U.S. \$7,000–22,000 for larger vehicles and trucks. However, conversion is technologically infeasible for some vehicles.

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's Brackler 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 eighteen 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, and 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 that 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 (Badische Zeitung 2009). 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 percent of Germans reject LEZs as being too bureaucratic and likely having little effect (DSM 2009). In an earlier survey, 70 percent of drivers stated that they hesitated to drive into an 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) and “*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, in anticipation of the stricter 2010 standards, all larger German cities are currently adopting even more restrictive LEZs. 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 EU has been regulating PM since the 1980s. Today, the EU has among the strictest limits on PM₁₀ worldwide. As European cities and local governments face high penalties for noncompliance with these limits, they are struggling to find effective measures to reduce PM₁₀ and PM_{2.5}. 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 Paulo (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 legislation and environmental concerns, London also recently established an LEZ whereby those cars that have low emissions are exempt from the 8-pound congestion charge. While New York City’s congestion

fee plans stalled in the legislature, San Francisco is currently debating a 6-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 PM_{2.5} or even PM_{1.0}, 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 PM_{2.5} regulation, while the EU is the strictest worldwide in terms of PM₁₀.²³ Meeting these standards requires 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.

Appendix: 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 United States 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 United States, 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 United States.

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 greenhouse gas (GHG) emissions, which while not directly regulating fuel use, often affect fuel use (An and Sauer 2004). The United States 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 Europe, a voluntary agreement between the EC and the European Automobile Manufacturers Association (ACEA) in 1998 set 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

²³As noted in the discussion of U.S. regulations, California's ambient PM₁₀ standards are approximately equal to those in the EU.

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 emissions standards are as stringent as the EU standards.

The United States introduced tailpipe emissions standards for CO, volatile organic compounds (VOC), and NO_x 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 emissions standards. While the United Nations Economic Commission for Europe (UN-ECE) had historically set EU-wide vehicle emissions 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+NO_x, NO_x and PM, establish six stages (Euro 1 to Euro 6, with Euro 6 taking effect in September 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 United States 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 2007.²⁴ 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 SO₂ 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).

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²⁴See Auffhammer and Kellogg (2009) for a recent summary of the U.S. fuel content regulations.

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