

Technical Appendix to

KEEP YOUR CLUNKER IN THE SUBURB: LOW EMISSION ZONES AND ADOPTION OF GREEN VEHICLES

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This is the web based online supplemental Appendix of the main article and consists of the following six sections:

Appendix A: Comparative Results of Recent Urban PM10 Studies

Appendix B: Characteristics of German Attainment Cities, Nonattainment Cities and LEZ

Appendix C: Average daily PM10 level by LEZ Treatment Status

Appendix D: Test of Alternative Specifications:

Appendix E: Sample Details on Geographical Matching Approach

Appendix F: Cost Benefit Analysis

Table A.1: Comparative Results of Recent Urban PM10 Studies

Study	Country	Station Type	PM 10 Sources				
			Motor Vehicle Exhaust	Resuspension (Dust)	Combustion (Industry and Individual)	Natural Sources	Other
Lenschow et al. (2001)	Germany (Berlin)	Traffic	38%	12% ¹	24%	12% ²	NA
		Background	23%	8% ³	33%	14% ²	NA
Querol et al. (2004)	EU	Traffic	35-55%	NA	15-25%	17-24%	NA
Querol et al. (2001)	Spain	Traffic	54%	NA	NA	30%	17% ⁴
Ferusjo et al. (2007)	Sweden	Traffic	36%	23%	14%	NA	26% ⁵
		Background	13%	23%	19%	NA	34% ⁵
Rodriquez et al. (2003)	Spain	Traffic	25%	33%	16%	11% ⁶	NA
		Background	8%	42%	20%	11% ⁶	NA
Chow et al. (1996)	USA (CA)	Traffic	30-42%	25-37%	NA	18-23% ⁶	NA
Harrison et al. (1997)	UK	Traffic	32%	50%	NA	NA	18% ⁷

¹The authors attribute 50% of PM10 levels to motor vehicles and then split this into 38% from emissions/tire abrasion and 12% from the resuspension of dust caused by traffic.

²The residual is attributed to natural sources such as pollen and wind-borne soil.

³The authors attribute 31% of PM10 levels to traffic and then split this into 23% from emissions/tire abrasion effect on background levels and 8% from resuspension of dust.

⁴Source is undetermined.

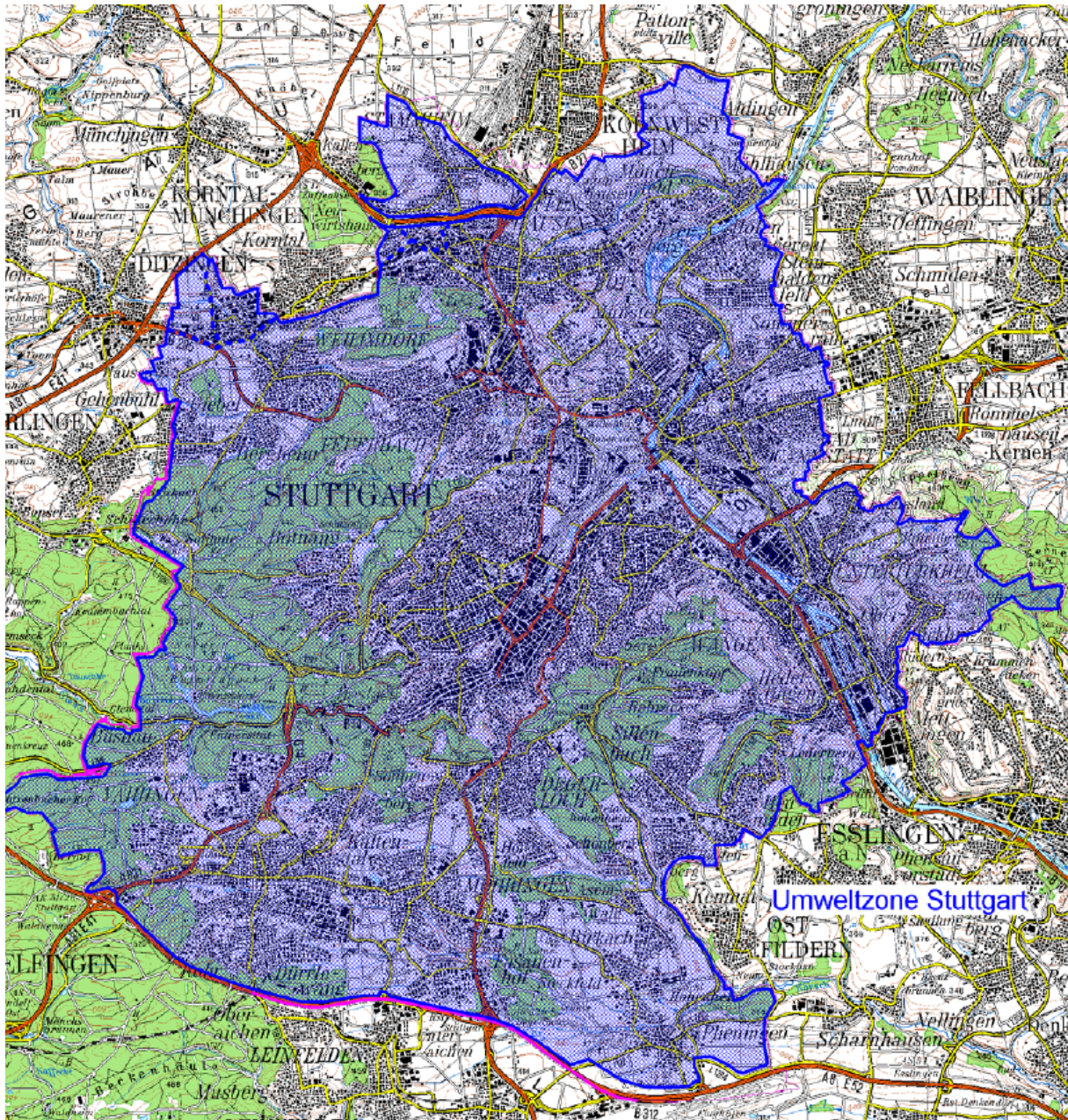
⁵Long range transport of pollution or dust particles from outside of Sweden.

⁶The specific natural source is marine aerosol.

⁷They identify the residual as secondary ammonium salts and are unable to determine whether these arise from combustion or are the effect of marine air.

Appendix B: Characteristics of German Attainment Cities, Nonattainment Cities and LEZ

Figure B.1: The LEZ of Stuttgart



Copyright: Landesvermessungsamt Baden-Württemberg, Bundesamt für Kartographie und Geodäsie 2003. The English term “Low Emission Zones” is commonly known in German as *Umweltzone* (Environmental Zone).

Table B1: Current and Future German LEZs

City	Start date	Excluded vehicles	Size of LEZ: new	Inhabitants that live within the LEZ	Dates of future restrictions (2nd, 3rd round)	Future excluded vehicles (2nd, 3rd round)
Berlin	1/1/2008	no sticker	88 km ²	1.1 mill	1/1/2010	red + yellow
Cologne	1/1/2008	no sticker	16 km ²	130,000	1/1/2010	red
Hannover	1/1/2008	no sticker	50 km ²	218,000	01/01/09, 01/01/10	red, yellow
Dortmund (Brackeler Road)	1/12/2008	no sticker + red	< 0.1 km ²	300	1/1/2010	not yet planned
Ilsfeld	3/1/2008	no sticker	2.5 km ²	4,000	1/1/2012	red
Leonberg	3/1/2008	no sticker	30 km ²	40,000	1/1/2012	red
Ludwigsburg	3/1/2008	no sticker	30 km ²	55,000	1/1/2012	red
Mannheim	3/1/2008	no sticker	7.5 km ²	93,900	1/1/2012	red
Reutlingen	3/1/2008	no sticker	<10 km ²	Unknown	1/1/2012	red
Schwäbisch Gmünd	3/1/2008	no sticker	5 km ²	20,000	1/1/2012	red
Stuttgart	3/1/2008	no sticker	207 km ²	590,000	1/1/2012	red
Tübingen	3/1/2008	no sticker	≈13 km ²	Unknown	1/1/2012	red
Pleidelsheim	7/1/2008	no sticker	7 km ²	7,000	1/1/2012	red
Bochum	10/1/2008	no sticker	58.1 km ²	150,000	end of 2010	red + yellow
Bottrop	10/1/2008	no sticker	≈25 km ²	Unknown	end of 2010	red + yellow
Dortmund	10/1/2008	no sticker	19.1 km ²	587,137	1/1/2011	red
Duisburg	10/1/2008	no sticker	≈43 km ²	Unknown	end of 2010	red + yellow
Essen	10/1/2008	no sticker	140 km ²	14,000	1/1/2011	red
Frankfurt	10/1/2008	no sticker	110 km ²	Unknown	01/01/10, 01/01/12	red, yellow
Gelsenkirchen	10/1/2008	no sticker	20 km ²	Unknown	end of 2010	red + yellow
Mülheim	10/1/2008	no sticker	≈14.2 km ²	Unknown	end of 2010	red + yellow
München	10/1/2008	no sticker	44 km ²	431,000	1/1/2010	red
Oberhausen	10/1/2008	no sticker	23.8 km ²	91,000	end of 2010	red + yellow
Recklinghausen	10/1/2008	no sticker	<20 km ²	Unknown	Unknown	Unknown
Bremen	1/1/2009	no sticker	7 km ²	56,000	1/1/2010	red
Heilbronn	1/1/2009	no sticker	≈22.5 km ²	Unknown	1/1/2012	red
Herrenberg	1/1/2009	no sticker	≈4 km ²	28,000	1/1/2012	red
Karlsruhe	1/1/2009	no sticker	≈ 12 km ²	Unknown	1/1/2012	red
Mühlacker	1/1/2009	no sticker	≈ 1.5 km ²	Unknown	2012	red
Pforzheim	1/1/2009	no sticker	≈ 2 km ²	Unknown	1/1/2012	red
Ulm	1/1/2009	no sticker	≈ 27 km ²	Unknown	1/1/2012	red
Düsseldorf	2/15/2009	no sticker	13.8 km ²	36,500	1/1/2011	red
Wuppertal	2/15/2009	no sticker	≈ 15 km ²	Unknown	1/1/2011	red
Augsburg	7/1/2009	no sticker	5.2 km ²	Unknown	1/1/2010	red
Neu-Ulm	11/1/2009	no sticker	≈ 2.7 km ²	Unknown	1/1/2012	red
Bonn	1/1/2010	no sticker	≈ 5 km ²	Unknown	7/1/2011	red + yellow
Freiburg	1/1/2010	no sticker	28 km ²	120,000	1/1/2012	red + yellow
Heidelberg	1/1/2010	no sticker	10.3 km ²	170,000	1/1/2012	red
Münster	1/1/2010	no sticker + red	≈ 1.5 km ²	Unknown	Unknown	Unknown
Osnabrück	1/4/2010	no sticker	14 km ²	7,000	1/4/2011	red
Pfintztal	1/1/2010	no sticker	31 km ²	18,000	1/1/2012	red
Dresden	2012	no sticker	4.2 km ²	6,500	Unknown	Unknown
Leipzig	1/1/2011	no sticker-yellow	≈ 239 km ²	Unknown	Unknown	Unknown
Cities with proposed LEZs (no final start date yet):	Arnsbach, Arzberg, Aschersleben, Bayreuth, Bernau, Brandenburg an der Havel, Braunschweig, Burgdorf, Burghausen, Castrop-Rauxel, Chemnitz, Cottbus, Darmstadt, Eberswalde, Erfurt, Erwitte, Frankfurt an der Oder, Gera, Görlitz, Halle (Saale), Hambach, Hamburg, Ingolstadt, Itzehoe, Jena, Kassel, Krefeld, Lahn-Dill, Landshut, Lindau, Ludwigshafen, Lutherstadt Wittenberg, Mainz, Magdeburg, Mühlheim an der Ruhr, Nauen, Neuruppin, Neuwied, Neuss, Passau, Potsdam, Regensburg, Rhein-Main, Schwandorf, Speyer, Trier, Warstein, Weiden, Weimar, Worms, Wuppertal, Würzburg					

Table B2: Characteristics of all Attainment and Nonattainment Cities

City	Avg. 2005 PM ₁₀ at highest polluting station	2005 Exceed- ance days	Violate limit in 2005- 06	Treatment status	LEZ start date	Population
Wascheid	12.0	0	0	Attainment		
Netphen	12.6	0	0	Attainment		
Neuglobsow	13.8	3	0	Attainment		
Simmerath	14.0	0	0	Attainment		
Welzheim	16.2	4	0	Attainment		
Andechs, Gde.teil Rothenfeld	16.5	4	0	Attainment		3,237
Dunzweiler	16.6	2	0	Attainment		974
Hummelshain	16.6	1	0	Attainment		641
Bad Arolsen/Kohlgrund	17.0	5	0	Attainment		
Wittenberge	17.3	2	0	Attainment		
Dreißigacker	17.5	0	0	Attainment		
Rehlingen-Siersburg	17.7	3	0	Attainment		15,805
Klötze	17.8	2	0	Attainment		5,243
Kiel	18.7	5	0	APO-no violation		234,470
Güstrow	19.4	4	0	Attainment		105,071
Saarlouis	19.6	3	0	Attainment		209,719
Westerland	19.6	7	0	Attainment		
Kempton (Allgäu)	19.7	8	0	Attainment		61,442
Pfullendorf	20.1	8	0	Attainment		
Soest	20.4	6	0	Attainment		308,211
Wörth	20.5	8	0	Attainment		17,500
Tauberbischofsheim	20.5	13	0	Attainment		
Gülzow	20.6	9	0	Attainment		1,288
Wilhelmshaven	20.8	11	0	Attainment		83,245
Ratingen	20.8	5	0	Attainment		
Leverkusen	20.8	2	0	Attainment		161,030
Zarrentin	20.8	9	0	Attainment		4,672
Solingen	20.9	7	0	Attainment		163,291
Naila	21.1	7	0	Attainment		8,305
Walsrode	21.1	8	0	Attainment		
Michelstadt	21.2	7	0	Attainment		
Zella-Mehlis	21.3	4	0	Attainment		12,245
Göhlen	21.3	11	0	Attainment		407
Tübingen	21.6	9	1	LEZ	3/1/2008	216,616
Biberach	21.6	13	0	Attainment		188,693
Klingenthal	21.6	9	0	Attainment		8,831
Pforzheim	21.7	13	1	'Future' LEZ	1/1/2009	119,168
Eisenach	21.8	10	0	Attainment		43,703
Jork	21.8	11	0	Attainment		
Völklingen	21.9	3	0	Attainment		40,794
Nettetal	22.1	8	0	Attainment		
Reidstadt	22.2	9	0	Attainment		
Eggenstein	22.3	10	0	Attainment		
Neuruppin	22.4	13	0	APO-no violation		
Wiesloch	22.4	12	0	Attainment		

Appendix B (cont.)	Avg. 2005 PM ₁₀ at highest polluting station	2005 Exceed- ance days	Violate limit in 2005- 06	Treatment status	LEZ start date	Population
City						
Dillingen	22.5	4	0	Attainment		21,431
Friedrichshafen	22.5	14	0	Attainment		
Kleinwallstadt	22.6	9	0	Attainment		5,823
Fulda	22.7	7	0	Attainment		219,600
Neu Zauche	22.7	16	0	Attainment		
Aalen	22.8	16	0	Attainment		
Bonn	22.9	4	0	'Future' LEZ -no violation	1/1/2010	313,291
Raunheim	23.1	12	0	Attainment		
Zeitz	23.1	16	0	Attainment		31,045
Hattingen	23.2	7	0	Attainment		
Wesel	23.2	15	0	Attainment		475,923
Radebeul	23.2	14	0	Attainment		33,091
Greiz	23.2	16	0	Attainment		115,387
Waiblingen	23.3	13	0	Attainment		
Bebra	23.3	10	0	Attainment		
Neustadt a.d. Donau	23.3	14	0	Attainment		12,738
Schwerte	23.5	9	0	Attainment		
Lünen	23.5	11	0	Attainment		
Osnabrück	23.6	13	1	'Future' LEZ -no violation	1/4/2010	163,330
Konstanz	23.6	18	0	Attainment		274,571
Plochingen	23.6	13	0	Attainment		
Delitzsch	23.7	12	0	Attainment		122,500
Buckow	23.8	21	0	Attainment		
Schwäbisch Hall	23.9	13	0	Attainment		189,579
Saalfeld	24.0	16	0	Attainment		27,861
Heidelberg	24.0	11	0	'Future' LEZ -no violation	1/1/2010	143,897
Burg	24.0	6	0	Attainment		25,000
Lingen	24.4	21	0	Attainment		
Meiningen	24.4	10	0	Attainment		21,448
Hof	24.4	21	0	Attainment		48,443
Hoyerswerda	24.4	20	0	Attainment		42,048
Bernburg	24.4	9	0	Attainment		64,860
Rostock	24.7	15	0	APO-no violation		199,325
Zwickau	24.7	18	0	Attainment		97,296
Hürth	24.7	8	0	Attainment		
Suhl	24.8	2	0	Attainment		42,283
Speyer	24.8	18	0	APO-no violation		50,567
Kulmbach	24.9	12	0	Attainment		76,890
Mönchengladbach	25.0	24	0	Attainment		261,216
Ulm	25.1	18	1	'Future' LEZ	1/1/2009	120,748
Schweinfurt	25.1	14	0	Attainment		54,097
Altenburg	25.2	27	0	Attainment		37,236
Coburg	25.4	15	0	Attainment		41,768
Aschaffenburg	25.6	12	0	Attainment		68,645
Wiesbaden	25.8	18	0	Attainment		275,085
Bernhausen	25.9	21	1	APO		13,216

Appendix B (cont.)	Avg. 2005 PM ₁₀ at highest polluting station	2005 Exceed- ance days	Violate limit in 2005- 06	Treatment status	LEZ start date	Population
City						
Bautzen	25.9	20	0	Attainment		148,945
Stralsund	26.2	22	0	Attainment		58,563
Heilbronn	26.2	22	1	'Future' LEZ	1/1/2009	121,498
Lindau (Bodensee)	26.3	28	1	APO		79,636
Emden	26.3	20	0	Attainment		51,666
Nauen	26.4	25	0	APO-no violation		16,674
Hanau	26.5	20	0	Attainment		88,251
Königs Wusterhausen	26.5	20	0	Attainment		33,201
Weißenfels	26.6	32	0	Attainment		73,624
Pirmasens	26.6	16	0	Attainment		42,761
Bamberg	26.7	20	0	Attainment		69,746
Freiberg	26.7	33	0	Attainment		144,094
Leonberg	26.8	16	1	LEZ	3/1/2008	45,537
Stendal	26.9	18	0	Attainment		130,436
Gelsenkirchen	27.0	24	0	'Future' LEZ	10/1/2008	267,418
Cologne	27.0	14	0	LEZ-no violation	1/1/2008	986,317
Mülheim	27.0	21	0	'Future' LEZ-no violation	10/1/2008	169,651
Zittau	27.0	31	0	Attainment		29,898
Arzberg	27.0	24	0	APO-no violation		5,893
Itzehoe	27.1	21	0	APO-no violation		33,800
Dessau	27.2	18	0	Attainment		77,914
Schwandorf	27.3	30	0	APO-no violation		144,644
Worms	27.5	27	1	APO		81,984
Würzburg	27.7	30	0	APO-no violation		134,080
Glauchau	27.8	24	0	Attainment		25,760
Norderney	27.8	17	0	Attainment		5,986
Aachen	28.0	18	0	APO		258,055
Wuppertal	28.0	20	0	'Future' LEZ	2/15/2009	358,813
Plauen	28.1	33	1	APO		68,614
Magdeburg	28.3	22	1	APO		229,344
Erlangen	28.3	22	0	APO		103,469
Gera	28.4	31	1	APO		103,446
Reutlingen	28.5	17	1	LEZ	3/1/2008	281,933
Saarbrücken	28.5	18	0	Attainment		340,702
Ratzeburg	28.8	28	0	APO-no violation		13,671
Datteln	29.0	30	0	Attainment		36,297
Krefeld	29.0	24	1	APO		237,336
Borna	29.1	31	0	Attainment		22,561
Neu-Ulm	29.1	34	1	'Future' LEZ	11/1/2009	163,477
Jena	29.6	29	1	APO		102,291
Landshut	29.7	39	1	APO		61,757
Nürnberg	29.7	33	0	APO-no violation		498,936
Weimar	29.8	35	1	APO		64,541
Trier	29.9	26	0	APO-no violation		100,198
Karlsruhe	29.9	22	1	'Future' LEZ	1/1/2009	285,756
Bottrop	30.0	33	0	'Future' LEZ	10/1/2008	119,195

Appendix B (cont.)	Avg. 2005 PM ₁₀ at highest polluting station	2005 Exceed- ance days	Violate limit in 2005- 06	Treatment status	LEZ start date	Population
City						
Fürth	30.1	30	0	Attainment		113,596
Ansbach	30.2	29	1	APO		40,531
Regensburg	31.6	37	1	APO		130,153
Ludwigshafen	31.7	37	1	APO		163,536
Görlitz	31.8	42	1	APO		57,418
Hagen	32.0	27	1	APO		196,295
Halle/Saale	32.2	51	1	APO		236,576
Kassel	32.2	48	1	APO		193,842
Aschersleben	32.2	38	1	APO		31,717
Freiburg	32.5	21	1	'Future' LEZ	1/1/2010	216,448
Münster	32.5	33	0	'Future' LEZ-no violation	1/1/2010	271,404
Frankfurt	32.5	48	1	'Future' LEZ	10/1/2008	648,925
Mannheim	33.4	43	1	LEZ	3/1/2008	307,847
Mainz	33.7	47	1	APO		195,178
Hamburg	33.7	46	1	APO		1,748,544
Darmstadt	34.0	42	1	APO		140,366
Erfurt	34.3	49	1	APO		202,723
Bayreuth	34.9	54	1	APO		73,617
Dresden	34.9	78	1	'Future' LEZ	2011	500,471
Potsdam	35.2	55	1	APO		148,126
Pleidelsheim	35.6	55	1	LEZ	7/1/2008	6,239
Essen	35.9	61	1	'Future' LEZ	10/1/2008	584,136
Frankfurt (Oder)	36.9	65	1	APO		63,177
Augsburg	37.1	61	1	'Future' LEZ	7/1/2009	262,492
Hannover	37.5	63	1	LEZ	1/1/2008	515,559
Düsseldorf	38.0	69	1	'Future' LEZ	2/15/2009	576,090
Berlin	38.1	74	1	LEZ	1/1/2008	3,399,896
Leipzig	38.2	75	1	'Future' LEZ	1/1/2011	504,798
Dortmund	39.5	82	1	'Future' LEZ	10/1/2008	587,870
Duisburg	40.0	83	1	'Future' LEZ	10/1/2008	500,217
Ludwigsburg	41.1	78	1	LEZ	3/1/2008	513,799
München	44.8	107	1	'Future' LEZ	10/1/2008	1,278,559
Stuttgart	54.5	187	1	LEZ	3/1/2008	593,244
Berghausen	NA	NA	1	APO		
Bernau	NA	NA	0	APO-no violation		
Burgdorf	NA	NA	0	APO-no violation		
Edertal-Hemfurth	NA	NA	0	Attainment		
Flensburg	NA	NA	0	Attainment		86,365
Heidenheim	NA	NA	0	Attainment		134,722
Heppenheim	NA	NA	0	Attainment		
Herrenberg	NA	NA	1	'Future' LEZ	1/1/2009	
Ilsefeld	NA	NA	1	LEZ	3/1/2008	8,307
Markgröningen	NA	NA	0	Attainment		
Mühlacker	NA	NA	1	'Future' LEZ	1/1/2009	
Possen	NA	NA	0	Attainment		
Sproitz	NA	NA	0	Attainment		

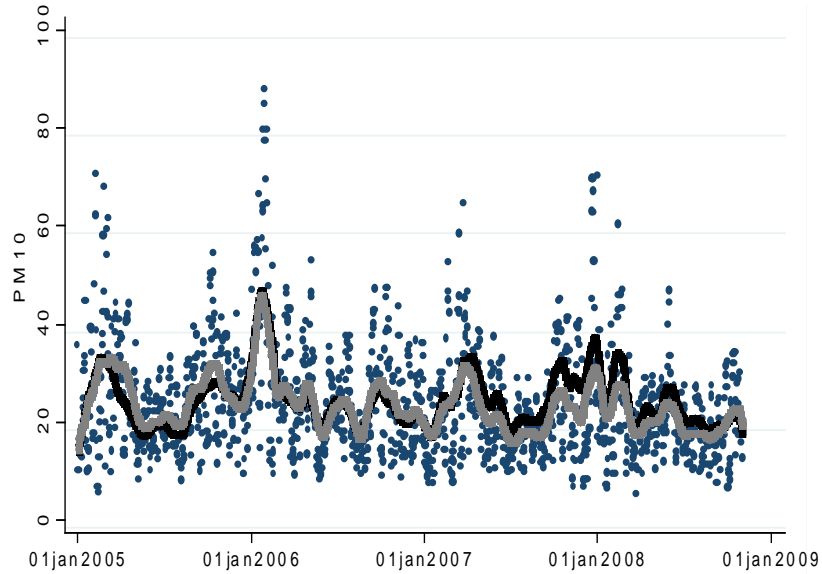
Appendix B (cont.)	Avg. 2005 PM ₁₀ at highest polluting station	2005 Exceed- ance days	Violate limit in 2005- 06	Treatment status	LEZ start date	Population
City						
Wlzbachtal-Jöhlingen	NA	NA	0	Attainment		

Notes: Shaded area used in PM₁₀ matching analysis. List only includes stations with sufficient data. 'Future' LEZs came into effect on or after 10/1/2008. 'No violation' refers to cities with APs despite not violating the PM₁₀ standard.

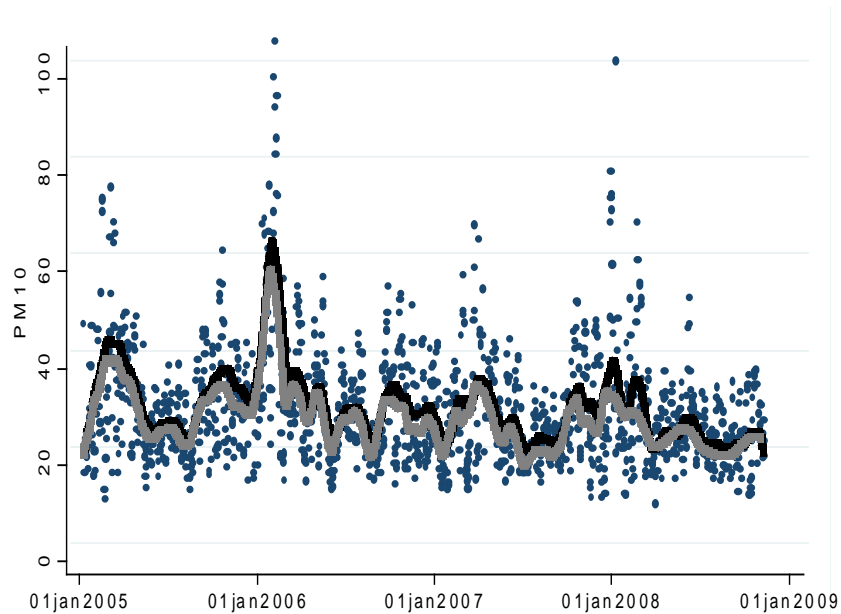
Appendix C

Figure: Average daily PM10 level by LEZ Treatment Status

Panel a: 2005 PM10 Matching Approach



Panel b: Geographical Matching Approach



Note: Each dot represents the average daily PM10 level of the samples described under each of the two approaches. (The sample of the 2005 matching approach is described in Section 4.2 and the sample of the Geographical approach is described in Section 4.3). The bold light grey line displays average daily PM10 level for control cities and the black bold black line the average daily PM10 level for treatment cities both estimated by the locally weighted scatterplot smoothing method with bandwidth of 0.04.

Appendix D: Test of Alternative Specifications:

With respect to robustness in covariates, the table below lists the effects of including/omitting the following set of regressors:

- Original regression including all covariates
- Without any weather covariates
- Without Holiday covariates
- Without Population covariates
- Without any covariate, except the necessary dummies to identify the Differences-in-Differences treatment effects,

Table: LEZ vs. Attainment cities – All Cities

Matching based on 2005 PM₁₀ in range 25 to 35

	With All Covariates		Without Weather Covariates		Without Holiday Covariates	
	Traffic stations (1)	Background stations (2)	Traffic stations (3)	Background stations (4)	Traffic stations (5)	Background stations (6)
LEZ treatment	-0.0910*** [0.0241]	0.00724 [0.0285]	-0.105*** [0.0244]	0.0100 [0.209]	-0.0912*** [0.0247]	0.00722 [0.0287]
Observations	6723	7704	6723	7704	6723	7704
Adj. R-squared	0.657	0.591	0.314	0.197	0.649	0.558

LEZ vs. Attainment cities – Cities > 100,000

Matching based on 2005 PM₁₀ in range 25 to 35

	With All Covariates		Without Weather Covariates		Without Holiday Covariates	
	Traffic stations (1)	Background stations (2)	Traffic stations (3)	Background stations (4)	Traffic stations (5)	Background stations (6)
LEZ treatment	-0.0686* [0.0302]	0.0448 [0.0354]	-0.0663* [0.0307]	0.0559* [0.0265]	-0.0685* [0.0310]	0.0454 [0.0357]
Observations	2896	4280	2896	4280	2896	4280
Adj. R-squared	0.653	0.612	0.300	0.193	0.641	0.608

Table: LEZ vs. Attainment cities – All Cities
Matching based on 2005 PM₁₀ in range 25 to 35

	With All Covariates		Without Population Covariates		Without Any Covariates	
	Traffic stations	Background stations	Traffic stations	Background stations	Traffic stations	Background stations
	(1)	(2)	(3)	(4)	(5)	(6)
LEZ treatment	-0.0910*** [0.0241]	0.00724 [0.0285]	-0.0910*** [0.0241]	0.00724 [0.0285]	-0.106*** [0.0248]	0.0102 [0.209]
Observations	6723	7704	6723	7704	6723	7704
Adj. R-squared	0.657	0.591	0.657	0.591	0.299	0.187

LEZ vs. Attainment cities – Cities > 100,000

Matching based on 2005 PM₁₀ in range 25 to 35

	With All Covariates		Without Population Covariates		Without Any Covariates	
	Traffic stations	Background stations	Traffic stations	Background stations	Traffic stations	Background stations
	(1)	(2)	(3)	(4)	(5)	(6)
LEZ treatment	-0.0686* [0.0302]	0.0448 [0.0354]	-0.0686* [0.0302]	0.0448 [0.0354]	-0.0669* [0.0313]	0.0564* [0.0265]
Observations	2896	4280	2896	4280	2896	4280
Adj. R-squared	0.653	0.612	0.653	0.612	0.283	0.181

Except where indicated in the column header, all regressions include year-month fixed effects, weather, holiday, station type and population covariates.

Regressions include data for April-October 2007 vs. 2008.

Robust standard errors in brackets are clustered by city, *** p<0.01, ** p<0.05, * p<0.1.

These alternative specifications of Table 8 show that our results are overall qualitatively similar to those when all covariates are included.

Appendix E: Sample Details on Geographical Matching Approach

For the regional regressions, the following control cities are used for each LEZ city:

Table E1: Control Cities for Individual LEZ Regressions

Stuttgart, Tübingen, Reutlingen & Ludwigsburg	Leonberg	Mannheim	Cologne	Hannover	Berlin
Heidelberg	Herrenberg	Heidelberg	Essen	Bremen	Leipzig
Karlsruhe	Mühlacker	Karlsruhe	Dortmund	Osnabruck	Dresden
Pforzheim			Dusseldorf	Göttingen	
Ulm			Duisburg	Braunschweig	
Heilbronn					
Freiburg					
Herrenberg					
Mühlacker					

Table E2: Effect of individual LEZs on log PM₁₀

Matching based on regional approach

	Berlin	Stuttgart	Hannover	Cologne	Mannheim	Reutlingen	Tubingen	Ludwigsburg	Leonberg
Traffic stations									
	(1a)	(2a)	(3a)	(4a)	(5a)	(6a)	(7a)	(8a)	(9a)
LEZ treatment	-0.120*** [0.0352]	-0.0288 [0.0218]	-0.0939** [0.0215]	-0.0742 [0.0416]	-0.0992 [0.0553]	-0.0582** [0.0246]	-0.0296 [0.0213]	0.0489* [0.0212]	0.0687 [0.0819]
Observations	4376	6507	2188	2996	2050	4836	4879	4880	1202
Adj. R-squared	0.59	0.712	0.579	0.685	0.633	0.667	0.647	0.668	0.436
Background stations									
	(1b)	(2b)	(3b)	(4b)	(5b)	(6b)	(7b)	(8b)	(9b)
LEZ treatment	-0.0442 [0.0494]	0.262*** [0.0243]	0.0516 [0.0330]	-0.0837 [0.0425]	0.114* [0.00894]	0.118** [0.0244]	0.159*** [0.0240]	0.0217 [0.0370]	
Observations	2186	1712	2735	2568	856	1712	1712	1712	
Adj. R-squared	0.591	0.619	0.461	0.612	0.639	0.596	0.591	0.593	

All regressions include year-month fixed effects, weather, holiday, station type and population covariates.

Robust standard errors in brackets are clustered by city, *** p<0.01, ** p<0.05, * p<0.1

Appendix F: Cost Benefit Analysis

F.1 Benefits

We use improvements in long-term mortality attributable to the decreased PM₁₀ in LEZs as our measure of benefits. Long-term mortality measures the decrease in life expectancy caused by long-term exposure to PM₁₀. We ignore acute mortality, or the increase in mortality due to a short-term increase in PM₁₀, since this may just be measuring the ‘harvesting’ effect where people who were near death die a few days or weeks earlier. To calculate the effect of PM₁₀ on long-term mortality, we use estimates of the link between PM₁₀ and mortality and morbidity in France, Switzerland and Austria. These estimates were derived by the World Health Organization (WHO) and have been used extensively in the epidemiology literature, i.e. in Medina *et al.* (2004), Kunzli *et al.* (2000), Seethaler (1999), van Zelm (2008).¹ Specifically, the WHO study found that for every one million residents in Switzerland and France, each 10 µg/m³ increase in PM₁₀ is associated with an additional 340 premature mortalities. Since these studies find that the effect of PM₁₀ on mortality is close to linear over the relevant range of PM₁₀, this means that each 1 µg/m³ increase in PM₁₀ is associated with 34 deaths per million residents. From these numbers using procedure described in section 7, we calculate the number of lives saved by each LEZ using the number of inhabitants within each LEZ. We multiply this by the EPA’s value of statistical life (VSL) of \$7,900,000 (2008\$)² to monetize these benefits (EPA 2000). Using this method, as summarized in Table A1 we find that the benefit from LEZs is approximately \$1.98 billion (\$1,978,395,825).

¹ These estimates are based on two cohort studies, Pope, et al. (1995) and Dockery, et al. (1993), as re-estimated by Krewski, et al. (2000). In their extensive review of the literature, the EPA singled out these two as the best studies for their cost-benefit analysis of the Clean Air Act Amendments (EPA 1999).

² This value has been adjusted to 2008 dollars from the value for 1999 specified in the cited report. Kiesner *et al.* (2012) estimate a range of VSL from 7 to 12 million.

Table F1: Value of mortality benefits from decreased PM₁₀

Fixed baseline mortality increment per 10 µg/m ³ PM ₁₀ and 1 million inhabitants					340
Deaths per person per 1 µg/m ³					0.000034
City	Traffic station coefficient	Avg 2007 Traffic station PM ₁₀	Amount PM ₁₀ decreases in 2008	Inhabitants of LEZ	Number of lives saved
Berlin	-0.1500 ³	28.86	4.33	1,300,000	191.33
Ludwigsburg	0.0489	34.65	-1.69	55,000	-3.17
Tubingen	-0.0296	31.26	0.93	78300	2.46
Reutlingen	-0.0582	38.12	2.22	78523.2	5.92
Stuttgart	-0.0288	33.01	0.95	590,000	19.07
Hannover	-0.0939	26.02	2.44	218,000	18.11
Leonberg	0.0687	33.42	-2.30	40,000	-3.12
Koln	-0.0742	32.98	2.45	130,000	10.82
Mannheim	-0.0992	28.43	2.82	93,900	9.00
Total number of lives saved		250			
		EPA Estimate			
Value of statistical life		\$7,800,000			
Value of lives saved		\$1,953,352,840			

This estimate of benefits is conservative for many reasons. First, we only count the improvement in mortality amongst people who reside within the LEZs studied. As our results show, however, PM₁₀ also decreased in traffic areas outside of LEZs, most likely because of the adoption of cleaner vehicles, so if these areas were also included the number of lives saved would be higher. If each city's entire population was used instead of just inhabitants of the LEZ, the benefits would jump to \$5.22 billion (\$5,217,522,677).

The second way in which our estimates are conservative is that we only consider long-term mortality. PM₁₀ is also associated with non-lethal morbidity, however. In the above studies, also health effects from respiratory hospital admissions, cardiovascular hospital admissions, adult chronic bronchitis, child bronchitis and adult and child asthmatic attacks are considered. If these conditions and parameters are included in our benefits calculation in the same manner as above,⁴ then Table A2 shows how our measure of the benefits increases by \$13,661,332.

F.2 Costs

³ This estimate is derived from the stations that reside inside of the LEZ of Berlin (column 3 of Table 14).

⁴ For the conditions that differentiate between adults and children, we adjust the population numbers, using 14% as the proportion of children under 14 in Germany.

<http://www.countryreports.org/people/ageStructure.aspx?countryid=91&countryname=>

To measure the costs LEZs have imposed on Germans, we estimate the total cost of upgrading vehicles to be able to enter the LEZs. Since we measure the health benefits realized between 2007 and 2008, we also look at the costs of upgrading vehicles over this time period. To do this, we use our spatial vehicle registration data to fit regressions of the change in share of green-sticker cars and trucks from 2008 to 2009 on distance from an LEZ. Since we don't want to count vehicles that would have switched to green sticker vehicles in the absence of the LEZ regulation, we use the change in share of green stickers for the point furthest away from an LEZ (0.0110 and 0.0828 at 244 km from an LEZ for cars and trucks, respectively) as the baseline change in share of green stickers. For each location, we subtract this 0.0110 (0.0828) from our regression's predicted change in share of green stickered cars (trucks). This is the change in share of green stickers due to the LEZ, which we then multiply by the number of cars (trucks) for that location in 2008 to get the number of new green cars attributable to LEZs. We sum these numbers for all locations to get the total number of new cars and trucks due to the LEZ and multiply this by the average cost for upgrading a vehicle (\$1,650 for cars, \$14,500 for trucks) to get the total cost of upgrading cars and trucks because of LEZs. In other words, we estimate cost using the following formula

$$Total\ Cost = \sum_{i=cars, trucks} p_i \sum_{j=1}^J N_{ij} (\widehat{C}_{ij} - C_{i0})$$

where i represents cars and trucks, j indexes counties, N is the number of vehicles in 2008, \widehat{C}_{ij} is fitted value of change in share of green cars, C_{i0} is the baseline change in share of green vehicles, and p equals the cost of upgrading each vehicle type.

We find that the total cost of upgrading cars is \$475,185,312 and the total cost of upgrading trucks is \$618,133,842. The combined total cost is \$1,093,319,154. This cost is nearly half of our primary measure of benefits, \$1,978,395,825. If one considers the benefits for those who live close to but outside of an LEZ, as well as morbidity benefits, then the benefits of LEZs will exceed the costs by even more.

Table F2: Value of morbidity benefits from decreased PM₁₀

Condition		Fixed baseline mortality increment per 10 µg/m ³ PM ₁₀ and 1 million inhabitants cases	Deaths per person per 1 µg/m ³	Willingness to Pay to avoid condition (1996 Euros)
Respiratory Hospital Admission		140	0.000014	\$7,870.00
Cardiovascular Hospital Admissions		255	0.0000255	\$7,870.00
Chronic Bronchitis Incidence (adult)		410	0.000041	\$20,900.00
Bronchitis (child)		4725	0.0004725	\$131.00
Asthmatic Attacks (children)		2500	0.00025	\$31.00
Asthmatic Attacks (adult)		6280	0.000628	\$31.00

Number of incidents avoided										
City	Traffic station coefficient	Avg 2007 Traffic station PM ₁₀	Amount PM ₁₀ decreases in 2008	Inhabitants of LEZ	Respiratory Hospital Admission	Cardiovascular Hospital Admissions	Chronic Bronchitis Incidence (adult)	Bronchitis (child)	Asthmatic Attacks (adult)	Asthmatic Attacks (children)
Berlin	-0.15	28.86	4.33	1,300,000	78.78	143.50	198.42	372.25	3039.26	196.96
Ludwigsburg	0.0489	34.65	-1.69	55,000	-1.30	-2.38	-3.29	-6.17	-50.34	-3.26
Tubingen	-0.0296	31.26	0.93	78300	1.01	1.85	2.55	4.79	39.13	2.54
Reutlingen	-0.0582	38.12	2.22	78523	2.44	4.44	6.14	11.52	94.09	6.10
Stuttgart	-0.0288	33.01	0.95	590,000	7.85	14.30	19.78	37.10	302.92	19.63
Hannover	-0.0939	26.02	2.44	218,000	7.46	13.58	18.78	35.24	287.69	18.64
Leonberg	0.0687	33.42	-2.30	40,000	-1.29	-2.34	-3.24	-6.07	-49.60	-3.21
Koln	-0.0742	32.98	2.45	130,000	4.45	8.11	11.22	21.05	171.83	11.14
Mannheim	-0.0992	28.43	2.82	93,900	3.71	6.75	9.34	17.52	143.03	9.27
Total incidents avoided					103.12	187.82	259.71	487.23	3978.00	257.80
Willingness to pay (1996 Euros)					\$811,540	\$1,478,162	\$5,427,949	\$63,828	\$123,318	\$7,992
Willingness to pay total (1996 Euros)			\$7,912,789							
Willingness to pay total (2008 USD)			\$13,661,332							

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