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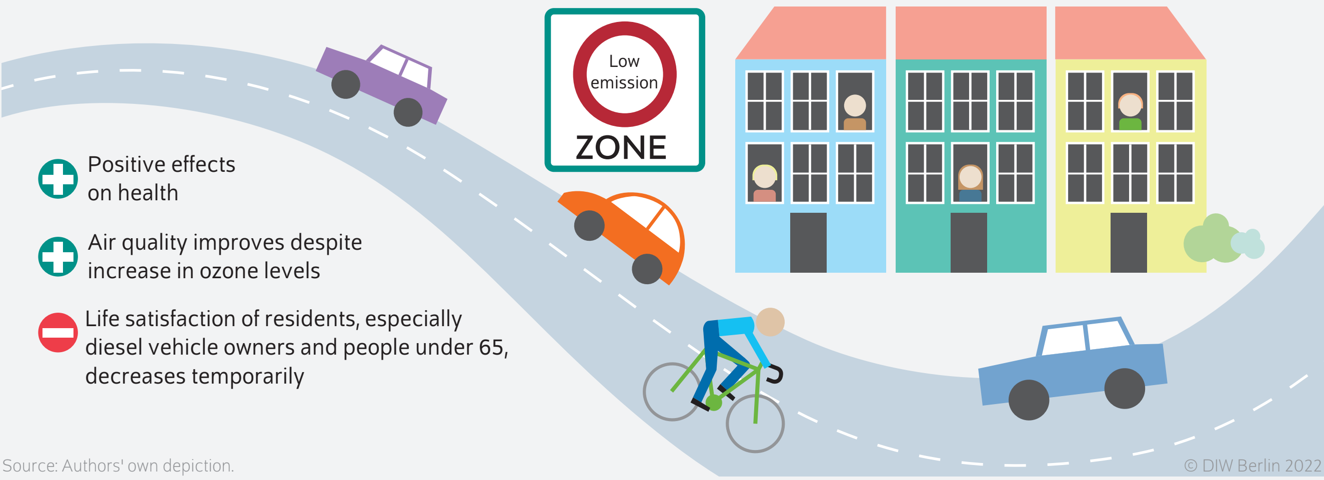
AT A GLANCE

Low emission zones improve air quality and health but temporarily decrease life satisfaction

By Luis Sarmiento, Nicole Wägner, and Aleksandar Zaklan

- Low emission zones' driving restrictions are meant to reduce air pollution to prevent health damage
- Study investigates the impact of German low emission zones on air quality and life satisfaction of residents via econometric analyses
- Low emission zones are effective at reducing traffic-related air pollution; however, they unintentionally increase ozone levels
- Life satisfaction of low emission zone residents decreases temporarily despite positive health effects
- Policy acceptance of low emission zones could be increased through information about their health benefits

Despite improved air quality and health, low emission zones decrease residents' life satisfaction



Source: Authors' own depiction.

FROM THE AUTHORS

"Low emission zones improve air quality and the health of the zones' residents. However, there are temporary adverse effects on their life satisfaction. Providing citizens with more information about the benefits of low emission zones would likely increase policy acceptance."
— Aleksandar Zaklan —

MEDIA

Audio Interview with Nicole Wägner (in German)
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Low emission zones improve air quality and health but temporarily decrease life satisfaction

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ABSTRACT

Air pollution results in high economic costs arising from its negative impacts on human health, especially in urban areas. Driving restriction policies such as low emission zones (LEZs) are designed to improve air quality. Indeed, empirical analyses in this Weekly Report confirm that LEZs reduce traffic-related air pollution. However, the analyses also reveal unintended adverse effects on secondary contaminants like ozone and on air pollution in adjacent areas. New evidence based on data from the Socio-Economic Panel (SOEP) shows that LEZs temporarily decrease their residents' life satisfaction despite positive health impacts. The magnitude of the decline depends on personal life circumstances: For example, there are stronger adverse effects on life satisfaction of diesel vehicle owners and people younger than 65. The results of this study suggest that mobility restrictions and the associated adjustment costs reduce policy acceptance. More effectively communicating the health advantages of LEZs to the population or utilizing transfer mechanisms such as public transport vouchers could mitigate these effects.

Air pollution causes health problems for the population, cardiovascular and respiratory diseases in particular, resulting in significant economic costs. Moreover, it reduces workers' productivity and students' educational success.[1]

Although the average air quality in Europe has been steadily improving over the past decades, EU limit values for certain pollutants are still continue to be exceeded in many regions (Box 1). Pollution levels are especially high in urban areas, particularly due to emissions from road transport. Regional driving restrictions are often introduced to reduce this pollution, for example in the form of low emission zones (LEZs). LEZs restrict motor vehicles with a high emission intensity from entering designated areas.

Over 200 European cities have introduced LEZs in the past decades. The first LEZs were introduced in 1996 in Sweden, but it was not until the 2000s that they gained importance in other countries, such as the Netherlands and Germany. These two countries have established national, uniform standards for LEZs, which is why a relatively large number of zones have been adopted in both countries. However, even without national standardization, many European capital cities use some variant of LEZs to improve air quality, including Madrid, Rome, Paris, London, Prague, and Vienna.[2]

This Weekly Report evaluates the effectiveness of LEZs in Germany and provides new evidence of their impact on the life satisfaction of LEZ residents.[3] Using air pollution data from the German Environment Agency (*Umweltbundesamt*, UBA) and survey data from the Socio-Economic Panel (*Socio-oekonomische Panel*, SOEP), causal effects of LEZs on air quality as well as residents' life satisfaction and health are estimated (Box 2).

1 Joshua Graff Zivin and Matthew Neidell, "Environment, health, and human capital," *Journal of Economic Literature* 51, no. 3 (2013), 689–730; Luis Sarmiento, "Air Pollution and the Productivity of High-Skill Labor: Evidence from Court Hearings," *The Scandinavian Journal of Economics* (2021); Emilia Simeonova, Janet Currie, Peter Nilsson, and Reed Walker, "Congestion pricing, air pollution, and children's health," *Journal of Human Resources* (2019): 0218–9363R2.

2 Claire Holman, Roy Harrison, and Xavier Querol, "Review of the efficacy of low emission zones to improve urban air quality in European cities," *Atmospheric Environment* 111 (2015): 161–169.

3 Luis Sarmiento, Nicole Wägner, and Aleksandar Zaklan, "Effectiveness, Spillovers, and Well-Being Effects of Driving Restriction Policies," *DIW Discussion Papers* 1947 (available online, accessed March 23, 2022; this applies to all other online sources in this report unless stated otherwise).

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Box 1

Legal framework for LEZs

The European Community set the legal framework for the uniform assessment of air quality in the 1990s. The Council Directive on ambient air quality assessment and management, passed in 1996, aimed to set limit values and alert thresholds to "avoid, prevent, or reduce harmful effects on human health and the environment," and to standardize assessment procedures and criteria.[1] Since 1999, several daughter directives were passed, which determined and defined limit values and measuring procedures for the first time.

Since 2010, the European Directive 20002/50/EG on ambient air quality and cleaner air for Europe has formed the legal basis for air quality standards, replacing the previous directives.[2] The limit values are legally binding upper limits; sustained non-compliance by member states can be sanctioned (Table 1).

To transpose the EU directives into national law, the German Federal Government issued the 22nd Ordinance of the Federal Immission Control Act (22nd BImSchV) in 2002. It determined limit values, calculation methods, and review mechanisms. For example, the German federal states are required to set up monitoring stations to check air pollution, and, if limit values are exceeded, to draft and to implement appropriate measures to reduce air pollution.

The legal basis for the introduction of low emission zones was created with the passing of the 2007 Immission Control Act (35. BImSchV) in October 2006. It has been in effect since March 2007.[3] The ordinance assigns motor vehicles (cars and trucks) to specific emission categories and allows driving restrictions based on the emission intensity of individual vehicles in accordance with Section 40 of the BImSchV. A vehicle's emission category is indicated by a colored sticker on its windshield: red stickers for the highest emission vehicles and green stickers for the lowest emission vehicles (Table 2).

When LEZs were initially being introduced, generally only vehicles without stickers were banned (stage 1). However, in the following years, red- and yellow-stickered vehicles were also banned (stages 2 and 3, respectively). The LEZ is enforced by the police and local authorities. Since 2014, drivers in violation are fined 80 euros (2008: 40 euros and one point in the traffic offender file).

Table 1

EU limit values for selected air pollutants

Pollutant	Max. permitted concentration	Reference period	Limit value/ target value	Permitted exceedences per year
Carbon monoxide (CO)	10 miligrams/ cubic meter	Highest 8-hour average per day	Limit value since 2005	–
Nitrogen dioxide (NO_2)	200 micrograms/ cubic meter	Hourly average	Limit value since 2010	18 days
Nitrogen dioxide (NO_2)	40 micrograms/ cubic meter	Annual average	Limit value since 2010	–
Ozone (O_3)	120 micrograms/ cubic meter	Highest 8-hour average per day	Target value since 2010	25 days in 3-year average
Coarse particulate matter (PM_{10})	50 micrograms/ cubic meter	Daily average	Limit value since 2005	35 days
Coarse particulate matter (PM_{10})	40 micrograms/ cubic meter	Annual average	Limit value since 2005	–

Note: Limit values must be attained and not be exceeded once attained, target value must be attained "where possible."

Sources: Authors' own depiction based on Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (available online).

Table 2

Emission categories in low emission zones

	No sticker	2	3	4
Diesel	Euro 1 or older	Euro 2, Euro 1 with particulate filter	Euro 3, Euro 2 with particulate filter	Euro 4 or better, Euro 3 with particulate filter
Gas	Without regulated catalyst	–	–	Euro 1 with regulated catalyst or better

Notes: Euro standards for diesel and gas motor vehicles according to Council Directive 70/220/EEC of 20 March 1970 on the approximation of the laws of the Member States relating to measures to be taken against air pollution by gases from positive-ignition engines of motor vehicles (available online).

Sources: Authors' own depiction based on Hendrik Wolff and Lisa Perry, "Trends in Clean Air Legislation in Europe: Particulate Matter and Low Emission Zones," *Review of Environmental Economics and Policy* 4, no. 2 (2010): 293–308.

1 Council Directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management (available online).

2 Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (available online).

3 35. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes, Verordnung zur Kennzeichnung der Kraftfahrzeuge mit geringem Beitrag zur Schadstoffbelastung – 35. BImSchV (in German; available online).

Box 2

Difference-in-differences estimation

The estimation results presented in this Weekly Report are based on a difference-in-differences strategy. In the difference-in-differences strategy, two groups are compared: the treatment group and the control group. The treatment group is affected by an intervention, in this case by the introduction of an LEZ. The control group is not affected by the LEZ and serves as an approximation of the treatment group in the hypothetical scenario that the policy never took place. The suitability of the selected control group is determined by the parallel development of the outcome variable in both groups before the introduction of the LEZ.

The empirical approach in the present analysis is based on an important advancement of the difference-in-differences method that accounts for the staggered introduction of policy interventions and possible dynamic effects of these interventions.[1] In the case of LEZs, it is important to consider these specifics because LEZs are not introduced simultaneously, but rather gradually over years (Figure 2). In addition, behavioral adjustments following LEZ implementation, such as changes in mobility behavior or the purchase of cleaner vehicles, can lead to dynamic effects, i.e., effects that change over time, on the outcome variable.

The causal effects of LEZs on individual air pollutants were empirically estimated using daily air pollutant values collected at more than 650 monitoring stations in Germany observed between 2005 and 2018. For this purpose, the measurements at *stations inside the zones* were compared with the measurements at suitable *control stations outside the zones*, and the differences between the two groups were compared before and after the introduction of the LEZ. To avoid spillover effects influencing the control stations' readings that distort the estimates, only control stations sufficiently far away from a LEZ are considered.[2]

The effects on life satisfaction and health were estimated using the same methodical approach. Here, the units of interest are individuals from the geo-referenced SOEP (instead of air pollution monitoring stations). The SOEP is a nationally representative annual survey of private households in Germany that has been conducted since 1984. In the geo-referenced version, respondents' places of residence can be included in the analysis,[3] which allows for a distinction between residents *inside and outside the LEZs*. The estimates are based on data from over 12,000 individuals who participated in the survey between 2005 and 2018.

1 Vgl. Brently Callaway and Pedro H. Sant'Anna, "Difference-in-differences with multiple time periods," *Journal of Econometrics* 225, no. 2 (2021): 200–230.

2 The control stations must be at least 25 kilometers away from an LEZ. This distance was determined empirically using a data-driven approach, see Sarmiento, Wägner, and Zaklan, "Effectiveness, Spillovers, and Well-Being Effects of Driving Restriction Policies."

3 Jan Goebel and Bernd Pauer, "Datenschutzkonzept zur Nutzung von SOEPgeo im Forschungsdatenzentrum SOEP am DIW Berlin," *Zeitschrift für amtliche Statistik Berlin-Brandenburg* 3 (2014): 42–47 (in German; available online).

Air pollution and low emission zones in Germany

Average concentrations of traffic-related air pollutants, such as carbon monoxide, coarse particulate matter, and nitrogen dioxide, have continually decreased over the past years (Figure 1). Nevertheless, the pollutant concentrations in urban areas covered by LEZs are notably above the national average over the entire observation period. For ozone there is an opposite trend: From 2016 to 2018, the annual average concentration of ground-level ozone increased, with urban areas typically below the national average.

Despite their decreasing trends, traffic-related air pollutants regularly exceed the EU limit values in Germany, particularly in urban areas. For example, the daily average concentration of coarse particulate matter, i.e., particles with a diameter of less than ten micrometers, exceeded the limit value in 89 German cities between 2005 and 2007. This included 52 large cities with over 100,000 residents, which amounts to 65 percent of all large cities in Germany. The annual limit value for nitrogen dioxide was exceeded in 54 cities during the same period.

The first LEZs were introduced in Berlin, Cologne, and Hanover on January 1, 2008, in response to the limit values being continually exceeded. Over the course of that year, 20 other German cities, among them Munich, Stuttgart, and Frankfurt, followed their example. By 2018, a further 30 cities had adopted LEZs (Figure 2) and as of 2022, there are 56 LEZs in Germany. Except for one, all zones reached stage 3 with the most stringent standards for vehicle emissions (Box 1).[4]

The introduction of the first LEZs impacted millions of private and commercial vehicles (passenger cars and trucks) that were no longer allowed to drive in certain areas. The early LEZs were met with widespread skepticism from the population and, in some cases, resistance from the business community. For example, automotive and retail lobbyists doubted that the restrictions would be able to noticeably decrease the concentration of coarse particulate matter. In addition, there were concerns about high bureaucratic costs and losses for the local economy.[5] Such concerns could be a sign of (initially) low acceptance of LEZs.

4 The first LEZs were increased to stage 2 or (directly) to stage 3 in 2009 and 2010.

5 Hendrik Wolff and Lisa Perry, "Trends in Clean Air Legislation in Europe: Particulate Matter and Low Emission Zones," *Review of Environmental Economics and Policy* 4, no. 2 (2010): 293–308.

LEZs are a suitable instrument for decreasing the adverse effects of air pollution on health

The positive effects of LEZs on traffic-related air pollution such as coarse particulate matter and nitrogen dioxide have already been proven.[6] DIW Berlin analyses show, however, that LEZs impact relevant secondary contaminants too, such as ozone, and air pollution in adjacent areas. The effects on ozone are relevant because ozone pollution is damaging to human health.[7] Effects on adjacent areas would extend the impact radius of LEZs beyond their borders (spillover effects). Such effects can arise from behavioral adaptations of drivers on the one hand, for example when they circumvent the LEZs and thus contribute to high pollution levels in the surrounding area. On the other hand, behavioral adjustments can decrease air pollution, for example when people residing outside of the LEZ switch to cleaner vehicles or other modes of transportation (such as public transport).

Empirical studies show that LEZs have a positive impact on the health of LEZ residents: The number of hospitalizations due to circulatory or respiratory conditions decreases within the zone.[8] LEZ residents spend less money on medications.[9] At the same time, the driving restrictions come with real costs: LEZ residents incur costs due to their individual mobility being limited, for example by having to buy a cleaner vehicle or to switch to other modes of transportation. In this study, we analyze the impact of LEZs on the health and subjective well-being of the affected individuals to contrast such costs with the individual benefits.

LEZs reduce traffic-related air pollution but increase ozone levels

This study confirms that LEZs are an effective instrument for reducing traffic-related air pollution. The results are based on air pollution levels recorded between 2005 and 2018 throughout Germany, both within and outside LEZs (Box 2). Within the LEZs, coarse particulate matter concentration decreases by around seven percent on average, whereas nitrogen dioxide concentration decreases by about nine percent. While the concentration of carbon monoxide also decreases after the zones are established, the change is not statistically significant.

Figure 1

Average concentration of pollutants in Germany, overall and within LEZs

Annual averages of individual pollutants (carbon monoxide in milligrams/cubic meter, nitrogen dioxide, coarse particulate matter, and ozone in micrograms/cubic meter)

Note: The first LEZs were introduced in 2008, followed by others until 2018.

Source: Authors' own depiction based on data from the Federal Environment Agency from 2005 to 2018.

Traffic-related air pollution is on a downward trend, whereas ozone levels are increasing.

While traffic-related air pollution decreases within the LEZs, the opposite is true for ozone: Ozone levels increase by around three percent on average due to chemical interactions between different precursor pollutants. For example, decreasing nitrogen dioxide emissions can result in higher ozone levels.[10]

An air quality index (AQI) is used to compare these opposing effects.[11] The AQI depicts the overall effect of the introduction

6 Hendrik Wolff, "Keep Your Clunker in the Suburb: Low-Emission Zones and Adoption of Green Vehicles," *The Economic Journal* 124, no. 578 (2014): F481–F512; Markus Gehrsitz, "The effect of low emission zones on air pollution and infant health," *Journal of Environmental Economics and Management* 83 (2017): 121–144; Nico Pestel and Florian Wozny, "Health effects of Low Emission Zones: Evidence from German hospitals," *Journal of Environmental Economics and Management* 109 (2021): 102512.

7 For example, the number of premature deaths caused by ground-level ozone is estimated to be 365,000 worldwide, cf. Marissa N. DeLang et al., "Mapping yearly fine resolution global surface ozone through the Bayesian Maximum Entropy data fusion of observations and model output for 1990–2017," *Environmental Science & Technology* 55, no. 8 (2021): 4389–4398.

8 Shushanik Margaryan, "Low emission zones and population health," *Journal of Health Economics* 76 (2021): 102402; Pestel and Wozny, "Health effects of Low Emission Zones."

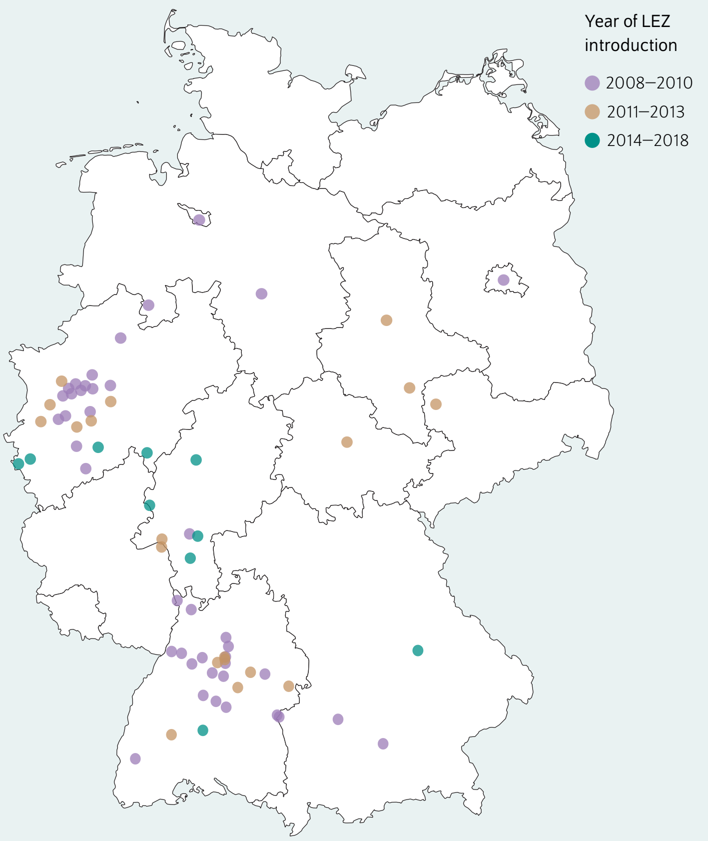
9 Alexander Rohlf, Felix Holub, Nicolas Koch, and Nolan Ritter, "The effect of clean air on pharmaceutical expenditures," *Economics Letters* 192 (2020):109221.

10 Ozone is a secondary pollutant that is not directly emitted from a source, but rather is created through chemical interactions with different precursor pollutants (such as nitrous oxides) in the lower atmosphere, cf. Paul S. Monks et al., "Tropospheric ozone and its precursors from the urban to the global scale from air quality to short-lived climate forces," *Atmospheric Chemistry and Physics* 15 (2015): 8889–8973.

11 This AQI maps all air pollutants simultaneously on a harmonized scale from 0 to 500. The higher the AQI, the worse the air quality. It is based on hourly pollutant concentrations and calculated according to US Environmental Protection Agency standards, cf. US Environmental Protection Agency, "Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI)," *Technical Report EPA* 454/B-18-007, Air Quality Assessment Division; Office of Air Quality Planning and Standards (2018) (available online).

Figure 2

Low emission zones in Germany by year of introduction



Note: The low emission zones in Bochum, Bottrop, Dortmund, Duisburg, Essen, Gelsenkirchen, Mülheim, Oberhausen, and Recklinghausen were combined into a common "Ruhr area" low emission zone in 2012. North of Stuttgart, the low emission zones in Ludwigsburg, Pleidelsheim, Markgröningen, Freiberg am Neckar, and Ingersheim were combined into a common "Ludwigsburg and surrounding areas" low emission zone.

Source: Authors' own depiction based on data from the Federal Environment Agency from 2008 to 2018.

Low emission zones have been introduced by cities in almost every German federal state.

of LEZs on air quality. Their introduction decreases the AQI by five points (11 percent), meaning that the air quality within the zones improves despite increasing ozone levels.

Effects on air pollution are dynamic and season dependent

The longer an LEZ is active, the stronger the observed effects on air pollution (Figure 3).[12] The nitrogen dioxide concentration decreases significantly in the second year following the introduction of the zone. Coarse particulate matter concentration also begins to decline significantly in the second year. Only the estimates for carbon monoxide are statistically uncertain and thus it is not possible to make a definite statement. In contrast, ozone concentration increases.

The effectiveness of LEZs also varies by seasons. During the winter months, the carbon monoxide level decreases significantly after LEZ adoption; this effect is not significant in summer, partially because internal combustion engines emit more exhaust fumes in cold temperatures.[13] This increases the effectiveness of the driving restrictions in winter. In contrast, the ozone level increases more strongly in spring and summer because more solar radiation and higher temperatures accelerate the ozone formation process.

Low emission zones influence air pollution in adjacent areas

To estimate the effects on pollution concentration in adjacent areas, the impact of LEZs on outside areas within 25 kilometers distance to a LEZ border is analyzed. The results indicate significant increases in ozone levels in adjacent areas that are of a similar magnitude as within the LEZs. The ozone increase in adjacent areas is especially pronounced in the summer months and almost twice as high as the annual average. LEZs do not cause any significant spillover effects for nitrogen dioxide or coarse particulate matter. Looking at the AQI, on average, no adverse effects of LEZs on air quality in adjacent areas can be identified. However, due to the increased ozone levels, the air quality in areas outside LEZs can worsen during the summer.

LEZs temporarily decrease residents' life satisfaction despite positive health effects

To estimate the impact of LEZs on residents' life satisfaction and health, a similar method as before was applied to geo-referenced data from the SOEP (Box 2).[14] Based on respondents' residence location and the survey date, it is determined if a respondent lives inside or outside of a LEZ at the time of data collection.

The results suggest that the introduction of a LEZ decreases the life satisfaction of residents by around three percent compared to their average life satisfaction before implementation of the zone. This effect is quantitatively meaningful: It amounts to about 15 to 20 percent of the effect of job loss on life satisfaction, one of the most decisive events for individual well-being.[15] The negative effect is visible in the first year of the driving restrictions and remains for four to five years before life satisfaction returns to its pre-LEZ level (Figure 4).

12 No significant effects are observed before the introduction of the LEZs. Thus, the assumption of parallel trends before the introduction of LEZs cannot be rejected for any pollutant, see Box 2.

13 Ricardo Suarez-Bertoa and Covadonga Astorga, "Impact of cold temperature on Euro 6 passenger car emissions," *Environmental Pollution* 234 (2018): 318–329.

14 The respondents' general life satisfaction is surveyed annually using a scale of 0 to 10. The respondents answer the following question: "How satisfied are you at present, all in all, with your life?" Zero means "completely unsatisfied," while ten means "completely satisfied." Health status, which considers diagnoses of specific diseases, has been surveyed every other year since 2009.

15 For estimates of the effect of job loss on well-being, cf. Sonja C. Kassenboehmer and John P. Haisken-DeNew, "You're Fired! The Causal Negative Effect of Entry Unemployment on Life Satisfaction," *The Economic Journal* 119, no. 536 (2009): 448–462.

Diesel car owners and younger adults experience an especially stark decrease in life satisfaction

The impact of LEZs on life satisfaction differs by the personal circumstances of those affected. Separate estimates show that the life satisfaction of diesel vehicle owners decreases much more than that of owners of gasoline cars vehicles. This is likely due to the stricter standards for diesel vehicles—and thus the higher probability of them being directly affected by driving restrictions.[16]

Stronger effects on life satisfaction are also visible for younger adults (under 65), whereas the life satisfaction of people over 65 is not affected. This is likely due to younger people's greater need for mobility, as they have to drive to work more frequently or have children in their household.

The adverse impact on life satisfaction is only weakly related to disposable household income, as it occurs across almost the entire income distribution. This could indicate that policy acceptance is limited among the general population. However, for individuals in the bottom quarter of the income distribution, no statistically significant effect on life satisfaction is visible, which could be due to the fact that the rate of vehicle ownership in this group is significantly lower than in the higher income groups.

LEZs decrease likelihood of developing hypertension

In addition, the effects of LEZs on the health of residents were investigated, focusing on hypertension as a risk factor for cardiovascular diseases.[17] Following the introduction of an LEZ, the likelihood of developing hypertension decreases by 4.6 percent,[18] with the likelihood for 60 to 80 year olds decreasing by up to eight percent. Additionally, a separate calculation shows that the adoption of LEZs has prevented at least 94,000 cases of hypertension throughout Germany.[19]

LEZs also impact life satisfaction of neighboring residents

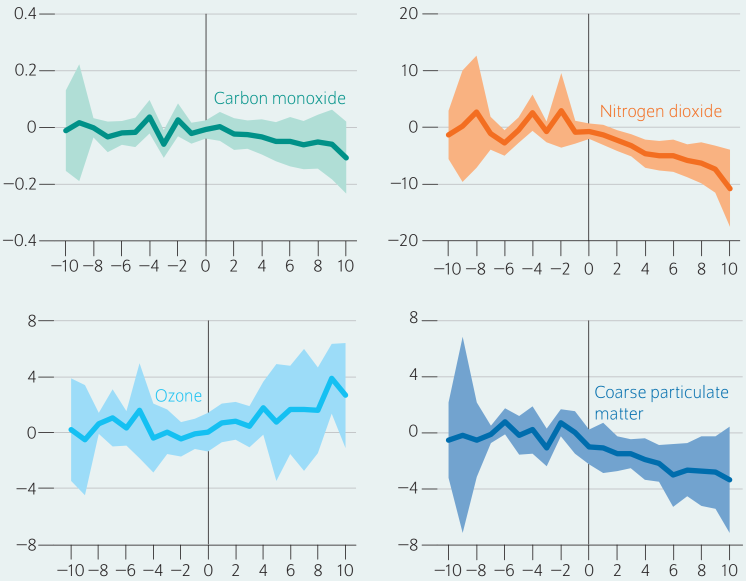
An LEZ does not only impact the people living within its borders; those living in the adjacent areas are alsoaffected: They potentially face reduced mobility in addition to the health costs of increased air pollution, as LEZs increase ozone levels in adjacent areas. To investigate this further, the impact of LEZs on the life satisfaction and health of people who reside within 25 kilometers of a LEZ was estimated.

The negative impact on general life satisfaction also affects people who live in close proximity to LEZs; their life satisfaction decreases to a similar degree as the life satisfaction of LEZ residents. Non-LEZ residents can also be affected by the driving restrictions, for example when they want to drive into the adjacent city center with an LEZ or if there is traffic displacement to neighboring areas. In contrast, no effects on the health of non-residents can be determined.[20] Thus, the results indicate that people living near LEZs experience limited mobility without reaping the health benefits from improved air quality.

Figure 3

Dynamic effects of low emission zones on air pollutants

Annual effect of low emission zones on individual pollutants (carbon monoxide in milligrams/cubic meter, nitrogen dioxide, coarse particulate matter, and ozone in micrograms/cubic meter)



Note: The horizontal axis represents the years before/after the introduction of a low emission zone, with 0 representing the first year following the introduction of the zone. The vertical axis shows the estimated effects of the low emission zone on the individual pollutants. Positive (negative) values indicate an increase (decrease) of the pollutant concentration following introduction of a low emission zone. The shaded areas indicate the 95-percent confidence intervals: An effect is statistically significantly different from zero (at the five percent significance level) if the confidence interval does not include the zero line.

Source: Authors' own calculations based on Federal Environment Agency data from 2005 to 2018.

Low emission zones decrease nitrogen dioxide and coarse particulate matter but increase the ozone level within its borders.

16 The actual costs incurred by a household to retrofit or purchase new vehicles are not directly captured in the SOEP. However, these costs should impact individual well-being because they decrease disposable income.

17 The empirical literature has already shown that LEZs lower residents' risk of cardiovascular diseases and supports the present results, cf. Margaryan, "Low emission zones and population health," and Pestel and Wozny, "Health effects of Low Emission Zones."

18 The positive health effects are visible in the first year of the LEZ and remain relatively stable over later years.

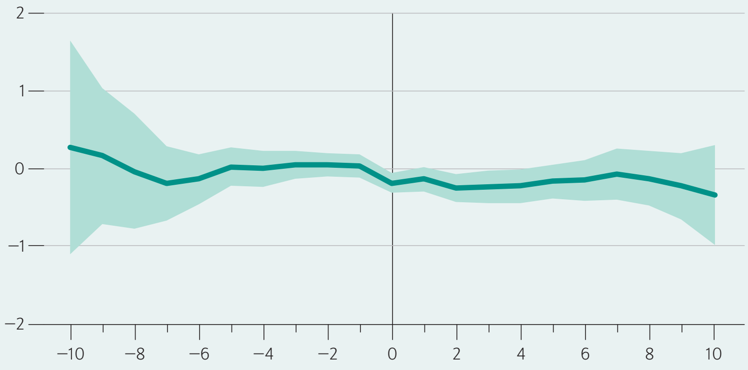
19 Before the first LEZ was introduced in 2008, the average hypertension rate was 31 percentage points. Together with the estimated percentage reduction, this results in a reduction of 1.4 percentage points after the introduction of LEZs. It was assumed that around 6.6 million people lived in an LEZ in 2018.

20 This suggests that the adverse spillover effects of air pollution are not sufficient to trigger adverse health effects.

Figure 4

Dynamic effects of low emission zones on general life satisfaction of residents

Annual effect of low emission zones on general life satisfaction on a scale from 0 to 10



Note: The horizontal axis represents the years before/after the introduction of a low emission zone, with 0 representing the first year following the introduction of the zone. The vertical axis shows the estimated effects of the low emission zone on the life satisfaction of its residents. Positive (negative) values indicate an increase (decrease) in the life satisfaction following introduction of a low emission zone. The shaded areas indicate the 95-percent confidence intervals: An effect is statistically significantly different from zero (at the five percent significance level) if the confidence interval does not include the zero line.

Source: Authors' own calculations based on Federal Environment Agency data from 2005 to 2018.

Introducing of a low emission zone decreases life satisfaction of its residents temporarily.

Conclusion: Design of LEZs has potential for improvement

This Weekly Report shows that LEZs decrease traffic-related air pollution effectively, both in terms of individual pollutants and overall air quality. At the same time, they cause unintended adverse effects, such as increased ozone levels within LEZs' boundaries and in adjacent areas. Policymakers should consider improving the design of LEZs to minimize such adverse effects. Possible strategies include seasonal driving restrictions during the winter months or increasing the scope of LEZs.

In addition, policymakers should develop measures to counteract the adverse impact on life satisfaction. For example, information campaigns about the clear health benefits of LEZs could be one option for mitigating the impact on people's well-being, as information on these societal benefits of environmental measures could positively influence their acceptance. To make the switch from private motor vehicles to environmentally friendly alternatives more attractive, public transportation and bicycle infrastructure could be expanded simultaneously with the introduction of an LEZ. Another option involves transfer mechanisms, such as public transport vouchers for residents, or financial support for the purchase of clean vehicles for hardship cases. The evidence in this Weekly Report is also relevant for similar policy measures, such as the driving ban on diesel vehicles.

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