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Evaluating urban traffic planning schemes in their effect on air quality: A policy comparison between Stockholm's congestion charges and Berlin's low emission zone.

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Abstract:
Despite the large theoretical corpus on approaches to dealing with negative externalities of road transport, there is a remarkable lack of connection to practically implemented road transport schemes.
This thesis gives two implemented road transport management systems, the congestion charging scheme as introduced in Stockholm and the low emission zone as introduced in Berlin, their place in the literature on negative externalities in road use. The need for a more differentiated evaluation and valuation of their effects on air quality is discussed by comparing analyses of air quality developments in the two cities, and by suggesting a life satisfaction approach to environmental quality in the analysis of the effectiveness of environmental transport schemes. The evaluation is then related to possibilities to ascertain public support. I find that integrated planning schemes, like the congestion charging scheme, that address transport demand over various channels and incentivize road users to change their travel behavior in the long run, promise higher improvements of air quality than single-minded schemes like the low emission zones.

Key words: externalities, road transport, air quality.

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List of Abbreviations

Abbreviation	Explanation
ANPR	Automated Number Plate Recognition
CC	Congestion Charges
CCS	Congestion Charging Scheme
CCZ	Congestion Charging Zone
CO_2	Carbon dioxide
CZ	Control Zone
ERP	Electronic Road Pricing (system)
LEZ	Low Emission Zone
NO_x / NO_2	Nitric oxides / Nitrogen dioxide
PM_x	Particulate matter of diameter smaller than *x* μm
TZ	Treatment Zone

1 Introduction

No question, motorised road transport is one of the greatest amenities of modern life. But with an increasing number of vehicles filling up road space and with climate goals that want to be met, the negative by-products of road transport need to be addressed. Different ransport and environmental management systems are being put in place and have gained attention. Nevertheless, the exposure to air pollutants continues to be a serious problem, in particular the exposure to those arising from road traffic emissions in inner-cities.

Common research questions addressing negative externalities arising from road usage therefore concern socially optimal levels of road use or best valuation options of the external cost. These serve as basis for designing theoretical schemes that aim at incorporating external costs into road users' private costs. However, practical implementations do not always coincide with theoretical reasoning. For this incongruity, transport policies are an obvious example. Unlike theoretical first-best solutions, road pricing schemes in the real world are imperfect and controls are necessary to check whether eventual benefits actually surpass implementation costs. Consequently, the evaluation of the implemented environmental and transport management schemes should be conducted in light of their theoretical predecessors.

With every policy implementation there is a spatial gap between legislations developed at national levels and the local effect of the implementations (Rapaport, 2002). This gap compares to the gap between theoretical solutions to externality problems and their practical applications and asks for a proper evaluation of the implemented schemes. Otherwise their effectiveness cannot be determined and there is no sound basis for replication.

Goals of urban transport planning schemes can be broadly categorised according to their economic, social and environmental consequences. Besides increased travel time for all traffic participants, negative externalities that arise from using motorised vehicles also include, for instance, increased noise levels and atmospheric pollution. These externalities have come into focus more and more as climate and health are distressed by anthropogenic pollution. The reduction of inner-city air pollution, above all other objectives, is important for addressing the effectiveness of urban transport planning schemes for several reasons. First, air pollution and climate change are closely connected – the same pollutants that drive climate change are emitted by vehicles. A majority of people seem to have acknowledged the importance of slowing down climate change. Consistency implies that those people should also be in favour of improving inner-city air quality.

Second, air pollution affects health of inner-city residents negatively. A major reason for the continued debate about improving air quality in cities is the well-documented causal chain between residents that are exposed to particle matter and cardiovascular diseases. Especially elderly people are predisposed to these diseases. In the course of demographic transition and rural-urban migration more residents of cities are going to belong to this age group. In order to lower health care costs it seems justified to give increasingly higher values to clean air.

Third, studies have shown that good air quality creates happiness (Welsch, 2006) and that a majority of people are willing to pay more for the improvement of their environment than for less congestion. Individuals should not forego their chance to increase their happiness. If individual life quality is noticeably reduced by air pollution, being freed of this influence might be seen as a human right (MacKerron & Mourato, 2009).

While plentiful comparisons of theoretical urban transport planning strategies are available (Anas & Lindsey, 2011; Johansson-Stenman, 2006), contrasts of actually implemented schemes are more scarcely strewn.

This thesis gives two implemented road transport management systems their place in the literature on negative externalities in road transport and discusses the need for a more differentiated evaluation and valuation of their effects on air quality.

The two policies to be analysed are congestion charges ('trängselskatt') as introduced in Stockholm in 2007 and the low emission zone ('Umweltzone') as introduced in Berlin in 2008. The experiences with these schemes are closely watched and are about to be adopted in other cities. Congestion charges for example are going to be implemented in Göteborg in 2013, and several German cities plan the introduction of low emission zones. Previous research that analysed effects of road pricing schemes focused on traffic flows and local economic effects, but more seldom on air pollution. Although short term analyses of both effects on air quality have been conducted, their methodological approaches were not convincingly laid out nor were they embedded in a theoretical framework of road externalities. Apart from the fact that they lack an academic scientific approach, they were conducted by local government authorities; therefore their objectiveness could be doubted. I contrast these analyses with a more sound temporal-spatial analysis borrowed from the evaluation of the impact of the London congestion charge on ambient air pollution. Since the aforementioned analyses lament the fact that they were conducted on a short term basis barely a year after the introduction of the schemes, I extend the analysis to several years after the introduction to level out possible temporary weather phenomena or abnormal seasonal influences.

Theory postulates that either scheme has an effect on inner-city air quality. However, following negative externality rationales, the congestion charging scheme with its direct effect on travel costs is expected to have a clearer influence. Further, I point out the possibilities of a life satisfaction approach to environmental valuation in the assessment of the impact of environmental management schemes on air quality.

A more detailed and wider comparative analysis is also expedient to gain public support and get road users in urban areas not only to accept the necessary adjustments to market failure in road usage, but also to encourage their long term support and possibly induce changes in their inner-city travel behaviour.

The structure of the thesis is as follows. Part two explains the externalities of road usage and their adjustments. Part three introduces the two policies. Part four looks at evaluation methods and data sources. Part five presents and discusses effects, and implications for behaviour and public acceptance of the two schemes, and part six concludes.

2 Negative Externalities in Road Usage and Policy Approaches

2.1 Externalities

The existence of external effects in road transport is not disputed. A convenient definition of external effects is provided by Verhoef (1994):

> *An external effect exists when an actor's (the receptor's) utility (or profit) function contains a real variable whose actual value depends on the behaviour of another actor (the supplier), who does not take these effects of his behaviour into account in his decision making process.*

Or, in terms of road use, when motorised vehicle drivers legitimately use roads they do not account for the unintentional effect which they exercise as a by-product on third parties.

External effects are borne on several levels: globally, road traffic pollutants contribute to climate change. Locally, direct air and noise pollution, water pollution and vibrations have to be borne by receptors; and higher traffic volumes that lead to congestion are endured by motorists collectively. The list of additional external effects can be extended with infrastructure damage, accidents, visual intrusion, and barriers to cyclists, pedestrians and wildlife. In a different but convenient categorisation it can be distinguished between intra-sectoral external costs, i.e. the external costs that road users impose on each other, and environmental externalities, which are the costs that road users impose upon the rest of society (Verhoef, 1994).

In using roads, individuals face their private costs of transport, which include for example travel time, costs for fuel, and costs of purchasing a vehicle. Without any external costs, road users' private costs would lead to a social optimum of allocated road space. The existence of external effects deflects allocation from this optimum and leads, in the case of negative external effects, to a consumption of road use that is too high compared to social optimum (Verhoef, 1994). The reason for the distortion is that there are no clearly defined property rights for the external effects. Normally, the market signals optimal allocation with prices that equal social costs or benefits, but in the case of external effects this signalling fails.

In order to correct this market failure and to incorporate costs to society into the consumption process of road usage, economic theory holds that road users should pay a charge for the externalities they cause. Taxes (for negative externalities) or subsidies (for positive externalities) should be applied to compensate the market imbalance and lead the market back to efficiency (Verhoef, 1994). An optimum can also be reached for example by quantitative restrictions. But the customary economic answer to internalising a negative externality is a Pigouvian tax (de Palma & Lindsey, 2011). An additional complication arises from optimal levels of usage in road transport which will be time and place related. Therefore an ideal Pigouvian tax should also be time-variant.

When talking about externalities in road transport, external costs are meant, i.e. negative external effects. Positive external effects, that are claimed to exist by automobile industry mainly, can by and large be dismissed as mere lobby assertions. If external benefits existed, this would imply the need to encourage road use by means of subsidies. By taxing and subsidising road use at the same time external benefits and external costs would offset each other. Benefits resulting from investment in infrastructure and lower transport costs are not actually external and should be clearly separated from the actual use of infrastructure. The interaction of transport with other sectors usually takes place on well-defined markets such that, summing up, no real external benefits of road usage can be distinguished.

Each motorised vehicle driving on a road emits pollutants into the atmosphere. Type and amount of pollutants depend on the technology of the vehicle in question as well as on the number of vehicles driving. Each additional road user also increases the time other users have to spend travelling. "For each pollutant, emissions per kilometre are a flat-bottomed, U-shaped function of speed with a minimum at an intermediate speed that depends on the pollutant" (Anas & Lindsey, 2011). As an effect, pollution will be higher when driving in congested conditions when speeds are normally slower than the minimum pollutant emission per kilometre. Since stop-and-go traffic prolongs travel time and emits more pollutants than driving steadily fast for a shorter time (Johansson-Stenman, 2006), "a road user should pay a charge corresponding not only to his or her own emissions, but also to the increased emissions and fuel consumption of other road users." (Yin & Lawphongpanich, 2006).

From the absence of well-established markets for pollution a challenge arises of how to value them. While exhaust emissions per se do not give rise to any costs, health impairment of residents of highly frequented roads or damage to natural environment as causal effects of exhaust emission do incur costs. The denser an area is populated, the larger costs of emissions will be. Detailed knowledge must be gained on the monetary values associated with the increased health care costs due to traffic pollutant and the real or perceived value of loss of natural environment as a result of exhaust emission. Only then can this value be transferred as cost to road users. In order to be inclusive, costs of exhaust emission should account not only for impacts on health, but also for destroyed building substance, agricultural production, and effects on the ecosystem. These are not the direct external effects but they ensue immediately from the externalities. Therefore, estimating the size of the external effect is challenging.

Spending on abatement or defensive actions can be taken to represent external costs if one assumes that they represent social willingness to pay for the pollution externalities. But it has been shown that this approach leads to serious underestimation of actual external costs. Contingent valuation, attributes cost values to emissions that are obtained by asking people how they value air quality or a reduction in air quality, for example in comparison to their income. One such approach that entails particular promise for the evaluation of urban environmental planning schemes is addressed in chapter 4.1.2 on the life satisfaction approach to economic evaluation.

2.2 Urban Transport Management Measures

In traditional transport literature, the focus is put on optimising use of a given infrastructure (Prost & van Dender, 2001). The idea was to price roads to reduce congestion externalities, but atmospheric pollution was not considered. From a societal perspective, large welfare gains can indeed be captured by transport policies addressing congestion because indirectly they affect emissions as well. Although a fundamental differentiation can be made between measures aiming at improving congestion and measures targeted at reducing environmental impacts, many measures, in practice, may address both goals or entail environmental improvements. If focusing on decreasing air pollution only total welfare may actually decrease because congestions are not addressed.

However, the theory of pollution pricing can be paralleled to congestion pricing since both present negative externalities. The following model proposed by Verhoef (1994) will serve as leverage to approaching environmental road management schemes. Three factors influence the level of the external costs: road activity, abatement actions, and defensive actions. Obviously, higher levels of road activity, that is, more vehicles driving on roads, will result in higher pollutant emissions. Knowing about the externalities they cause, road users can commit to abatement actions, for example in the form of installing cleaner technologies to their vehicles. Similarly, people exposed to externalities can engage in defensive actions, for example by relocating to less traffic dense areas or by installing air filters in their apartments. Further determinants of inner-city air pollution are meteorological conditions, but the weather is not within the sphere of influence of policy decisions.

This implies that basically, the government has three ways to reduce external costs: stifling the level of activity, or increasing defensive actions, or increasing abatement actions. Since abatement actions that road users engage in accrue to their private costs, policy measures to increase abatement directly shift costs to producers of the externality. Inducing outlays on defensive actions, on the other hand, shifts costs to the society, thereby increasing gross external costs (i.e. the sum of external costs of pollution and the induced expenditures on defensive activities). While victims of emissions generally exhibit efficient defensive behaviour, producers of the externality usually do not act efficiently. The level of pollutant production will be too high and abatement too low. Therefore, government action should take place in stimulating abatement and reducing emission at the source by stifling road activity.

Adding a tax that amounts to the size of the negative externality to private costs allocates road usage at the socially optimal solution. It was mentioned above that the negative externalities differentiate by time and vehicle technology, and therefore the optimal tax should vary as well. The most efficient way to achieve this is by way of a flexible, automated electronic road pricing system (ERP), be it for congestion or pollution externalities. While charges related to the emissions factor of vehicles or taxes on fuel deal only with pollution (and might in fact be quite effective for environmental externalities but not for congestion externalities), congestion charges deal with the number of vehicles. They do, however, affect pollution by way of allowing increased driving speeds at lower pollutant emission per kilometre. Ideally, a first-best tax option recognises and incorporates both types of externalities and is implemented by a first-best charging mechanism, an ERP, although this might imply substantial technical difficulties (Oberholzer-Gee & Weck-Hannemann, 2002).

2.2.1 Charges on Pollution

Following this theory, the ideal option is to impose the full external pollution cost on the respective road user who causes the pollution. Such a detailed splitting of contribution is, however, an elusive undertaking and not feasible since the real extent to which each vehicle user contributes to atmospheric pollution is impossible to extract. The contribution can on the other hand be calculated as a proxy. Doing so takes into account factors such as the technology of the vehicle or the time that is spent on the road or in a specific area. An approximation is achieved by assigning a “per vehicle kilometre emission factor” to the different kinds of vehicle technologies (Prost & van Dender, 2001). This emission factor is often assumed to be constant. More realistically, it should be allowed to vary with speed and the number of stops in a trip, since both affect average emission per kilometre. In combination with the travelled distance and an exposure factor of the environment, the emission factors give the environmental damage done by travelling per motorised vehicle (Johansson-Stenman, 2006).

A pollution related road pricing scheme has to be directly connected to the pollutants emitted in order to reduce emissions significantly. For efficiency, a differentiation between car types is necessary such that more efficient ones are charged with lower taxes (COWI A/S, 2002). This means that an ERP, if it was to be used for environmental externality purposes, should be able to distinguish between vehicle types and vehicle speeds within the charged zone as a prerequisite for following the polluters-pay principle.

Alternatively, in the absence of viable technological installations, a second best option in form of a common regulatory fee for all vehicles can be inflicted (Verhoef, Nijkamp, & Rietveld, 1995). Such a fee is necessarily less efficient than a differentiated tax since a common pollution fee for all vehicle types does not provide incentives to switch from more polluting vehicles to less polluting ones – it optimises neither abatement activities nor the amount of vehicles. On the contrary, if common fees apply, road users might be encouraged to use more polluting vehicles, for example if those are the more prestigious or faster ones (Verhoef, Nijkamp, & Rietveld, 1995).

Since pure pollution charging is not feasible, transport pricing policies experiment with cost approximations, legislative restrictions and other options that do not focus on environmental targets in order to achieve the desired result. A useful option, if direct charging policies are not possible, are fuel taxes, which follow a similar approach, but are not implemented at the actual road user level. Fuel taxes concern a necessary complement to road usage and pollutant emission and are therefore a policy measure that attempts to indirectly steer the externality-generating activity (Wijkander, 1985).

2.2.2 Charges on Congestion as an Implicit Pollution Charge

Of the factors influencing air pollution, congestion charges tackle the number of vehicles and count on the positive correlation between congestion and pollutant emission to solve the externality problem. By introducing congestion charges, the number of vehicles that enter the zone should be reduced to approach socially optimal levels of road traffic, and ensuing from this, congested driving conditions that increase fuel consumption are expected to occur less often. Both effects have the potential to reduce pollutant emission.

As in the case of pollution charges, an optimal charge would make use of ERP and adjust the charge to current traffic conditions since the ideal charge varies with time of day, season and traffic intensity (Anas & Lindsey, 2011). During traffic intensive morning and afternoon rush hours, the charge should be higher since the more congested driving conditions increase external costs of pollutant emission.

More all-encompassing effects could be gained by differentiating charges not only by time, but also by vehicle type, i.e. a hybrid scheme of pollution and congestion charges as it is in place in Stockholm. Charging more environmental-friendly vehicles a lower tax could add extra incentives to shift to low-energy vehicles (Erdmenger, Hoffmann, Frey, Lambrecht, & Wlodarski, 2010). By differentiating the charges by vehicle type, a more direct effect on air pollution can be achieved by encouraging road users to engage in abatement activities, apart from reducing the number of vehicles on the road. Exempting vehicles with lower emission factors or those driving on alternative energy pushes vehicle owners to switch to those vehicles in order to circumvent the charges. On the other hand, exempting clean vehicles completely from charges undermines the efficiency of the charge since this would mean that congestion externalities, to which clean vehicles contribute as much as standard vehicles, remain unaddressed (Anas & Lindsey, 2011). Even a zero-emission vehicle should pay a tax related to the increased emissions it causes other drivers to emit in the more congested streets.

Combining charge collection with electronic enforcement systems such as ERP can reduce emission additionally because queues at payment stations are abolished and speed reductions and accelerations are minimised (Anas & Lindsey, 2011).

2.2.3 Non-pricing Traffic Planning Measures

It was established above that government actions should take place in stimulating abatement and reducing emission at the source. To do this, transport management measures can be identified in three main policy fields: direct and indirect demand management, and supply side oriented policies (Verhoef, Nijkamp, & Rietveld, 1995). Any pricing or taxation on the direct activity or on related, externality-producing goods would be categorised as direct demand management Also some non-pricing measures to dis-incentivise driving or public marketing activities to change people's attitudes towards motorised vehicle use manage demand directly. This includes controls on stationary traffic (limiting parking space in cities to lower traffic volume), restrictions on moving traffic (speed restrictions, traffic collars, and traffic mazes), a hierarchal network of streets (pedestrians or cyclists have precedence) or permits for residents (Jones & Hervik, 1992). Indirect demand management addresses substitutes of road transport and includes for example the stimulation of demand for public transport services or encouragement to use bicycles for inner-city trips by including them in spatial urban planning. Supply-side measures include fuel quality controls or policies encouraging clean technology production, for example by way of introducing vehicle emission standards.

For inducing behavioural changes, non-pricing policy measures might in fact be preferred, or at least offer a complement to explicit pricing strategies to reduce emission. They are a good alternative if road pricing fails to gain public support due to extra costs imposed on road users. Low emission zones fall under this category of traffic planning measures. They are part of a set of measures that have been proposed by the European Union in order to not exceed critical air quality values. Low emission zones are areas which may only be entered by vehicles with certain emission standards. Vehicles that do not meet these standards are restricted from access to these defined areas. Similar to pollutant-related charges, they address external costs from the abatement-side. Compliance with regulation forces vehicle owners to install particle filters or to switch to cleaner technologies. Success of and compliance with this regulation depends on enforcement. Customarily a visual boundary is set up by road signs. Without a believable threat of control and penalty, vehicle owners will be tempted to breach the regulation and enter the zone without corresponding emission standard.

Economic theory proposes that, in the case of negative externalities, a tax in the magnitude of the externality is the best option to incorporate the externality into producers' cost function. A policy measure that does not impose such a tax must, per definition, be less effective. The only costs that are imposed by an LEZ are the costs of securing compliance, for example one-time costs of installing particle filters, purchasing the appropriate emission label or buying a cleaner car. Of course these costs might implicitly incorporate external costs into road users' private cost functions, but they do not represent the actual external costs caused by each road user's level of activity. The costs are instead determined by market prices of clean vehicles, instalment of particle filters or administrative costs of issuing an emission label.

This policy functions as an incentive for car owners to convert to low-emission or alternative-fuel vehicles more quickly. Even if the market has already developed cleaner vehicles, the nature of motorised vehicles as long-term investment implies that there is a "time-lag whilst the vehicle stock is being replaced" (Transport and Travel Research Ltd., 2006). In the meantime, LEZs are mechanisms that accelerate this transition. Vehicle owners might be enticed to buy a new alternative-fuel car earlier than they would have if the policy had not been in place.

The total of policy measures as summarised in Table 1, pricing and non-pricing, demand- and supply-managing, should not be seen as separate instruments; rather they support each other as complementary measures. Implemented as a combined urban transport management package, they tackle externality production at all possible leverages and, thus, deliver better results.

Table 1: Overview over urban traffic planning measures and their effects (cf. Verhoef, Nijkamp, & Rietveld, 1995).

		Traffic Planning Action	**Targeting**		**Effect on Emissions**
			Level of road activity	**Abatement**	
Direct Demand Management	**Pricing Measures**	Congestion Charges as implicit pollution charges	X		fewer vehicles and better speed/emission relation
		Pollution Charges		X	cleaner technologies and reduced travel distance (if incorporated in charge)
		Combination of Pollution and Congestion Charges (with ERP that recognises vehicle types, speeds, and distances)	X	X	less road activity and cleaner technologies
		Common pollution fee	(X)	(X)	evasion of fee by cutting car use; in combination with exemptions for clean vehicles, reduced emission by switching vehicle type
		Fuel taxes	X	X	reduce mileage (to reduce fuel use), switch to alternative fuel types
	Non-pricing Measures	Low emission zones		X	switch to cleaner technologies
		Traffic calming and speed limits, limited parking space	(X)		lower speeds, less car travel
		public opinion campaigns	(X)	(X)	behavioural change
Indirect Demand Management		increase public transport services, bicycle lanes	X		behavioural change, switch transport mode
Supply Management		fuel quality control, emission standards		X	replacement of vehicle fleet with cleaner technologies (long-term)

3 The Two Policies: Design and Implementation

The measures adopted in Stockholm and Berlin can both be filed under regulatory controls on moving traffic. The congestion charging scheme in Stockholm is clearly a direct pricing method. The low emission zone in Berlin is a non-pricing scheme which requires users to hold a permit in the form of a vehicle emission label in order to enter the zone. It therefore puts a restriction on vehicle types and technologies that may enter. Since the labels are sold at the cost of administration, the LEZ is rather a non-pricing measure, although indirect costs may be incurred by the policy in that the vehicles might need retrofitting to conform to required emission standards.

3.1 Stockholm: Congestion Charges[1]

The congestion charge in Stockholm applies to vehicles that want to get access to the inner-city ring (Figure 1). Its major aim is to control traffic volumes that enter this area (tempting to lower external costs at the road activity level), but environmental improvements are mentioned as a primary objective as well (Eliasson & Hugesson, 2006).

The Stockholm scheme was introduced in 2006 with a seven-month trial period ("The Stockholm Trial") and permanently installed in August 2007 after Stockholm's citizens had voted for the implementation of the charge. It has several interlinked components among which the introduction of congestion charges, increasing public transport and extending park-and-ride facilities. To be prepared for increased numbers of customers, extended public transport services were built and organised to be available when the trial began (Anas & Lindsey, 2011). Cameras at the streets that cross the cordon capture each passing vehicle by Automated Number Plate Recognition (ANPR).

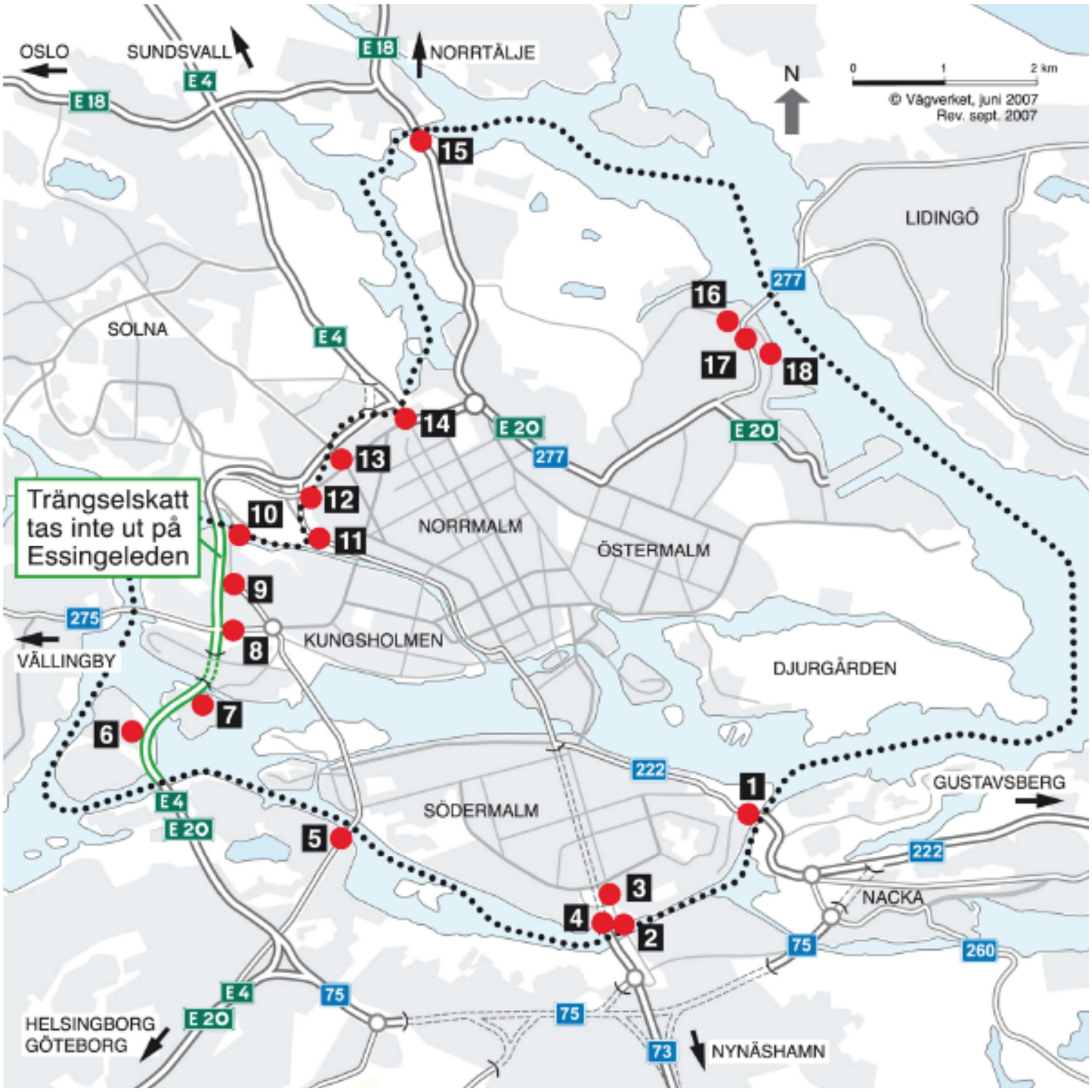
Each passing of the cordon, into town as well as out of town, has to be paid. Payment is made electronically such that it is not necessary to enforce compliance otherwise. The charging mechanism thus corresponds to the first-best charging option. Electronic payment does not necessitate other compliance measures. There is no charge on the E4 and E20 since those are pass-through highways. Also, there is no charge over the bridge to and from Lidingö since the bridge is the only connection to the main land. All registered Swedish vehicles have to pay, with certain exceptions: motorbikes, hybrid and electric vehicles, buses, military and emergency vehicles. In fact, "[e]xemptions and tax-regulations have changed over time in such a way that the average charge has decreased [… by] 16% in real terms since 2006" (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2010). Exempting clean vehicles is an attempt to stimulate abatement activities to aid lower traffic volumes in reducing external costs. Peak prices are 20 SEK during morning and afternoon rush hours. Every thirty minutes before and after peak prices are charged with 15 SEK. During other times between 6.30am and 6.30pm, the charge is 10 SEK (Table 2). A maximum of 60 SEK is levied per day and per vehicle. No taxes are levied at night time, on public holidays and in July (Transportstyrelsen, 2012).

Table 2: Prices and times of congestion charges in Stockholm (Transportstyrelsen, 2012).

Times	Price
06.30–06.59	10 SEK
07.00–07.29	15 SEK
07.30–08.29	20 SEK
08.30–08.59	15 SEK
09.00–15.29	10 SEK
15.30–15.59	15 SEK
16.00–17.29	20 SEK
17.30–17.59	15 SEK
18.00–18.29	10 SEK
18.30–06.29	0 SEK

[1] An environmental zone different from the one in Berlin has been in place in Stockholm since 1996. It only applies to diesel-fuelled heavy vehicles such as busses and lorries (>3.5t) who are banned from entering (Rapaport, 2002). For this purpose population dense urban areas with important buildings and green spaces were defined as sensitive environment that were impaired by excessive pollutant exposure.

Figure 1: Map of Stockholm and congestion charging zone (Transportstyrelsen, 2010).[2]



3.2 Berlin: Umweltzone (Low Emission Zone)

Since the EU directive on inner-city air quality (air quality framework 1996/62/EC) has been adopted into German legislation, exceeding the maximum value that was determined for air pollutant concentrations constitutes a law infringement. This forced municipalities and cities that recorded numerous exceedances to act, with the result of the construction of LEZs. In Berlin, European maximum permissible levels of particulate matter and nitrogen dioxide were exceeded at all major streets for several years in a row (Lutz & Rauterberg-Wulff, 2009).

Low emission zones are the favourite measure to constrain inner-city air pollution in Germany (Kuhlmey & Van Stegen, 2008). As of January 2012, 42 environmental zones exist in

[2] Red pricks: control stations with ANPR; black, dotted line: congestion charging zone

Germany, Berlin being one of them. An analysis of the cities particle emission structure recognised that more than half the particle emissions originate from urban sources, topped by traffic (Helmers, 2009). Therefore, introducing the LEZ is connected to high expectations concerning the reduction of emissions.

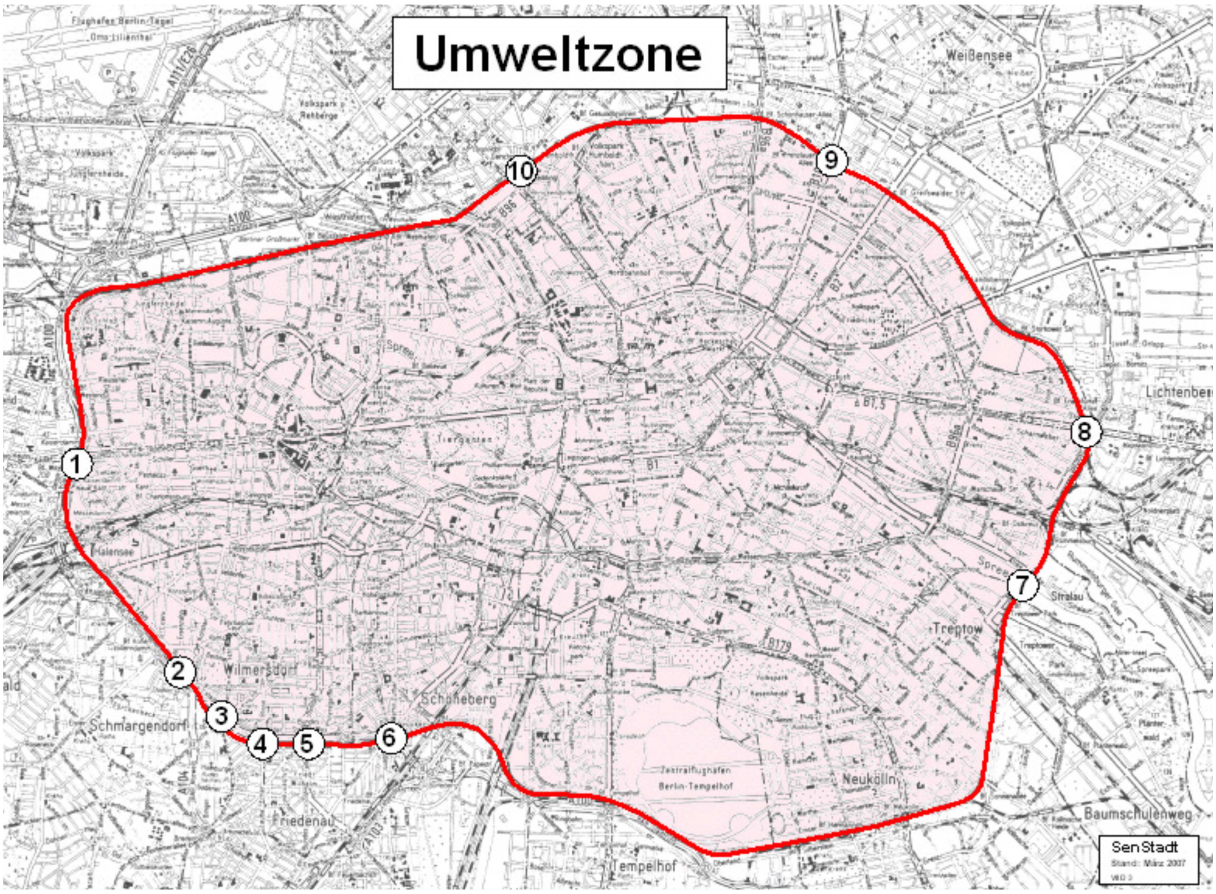
The expressed target of the LEZ is modernising the vehicle fleet, addressing external cost via encouraging abatement activities. Unlike congestion charges, the low emission zone does not take into account the contribution of the congestion factor towards pollution. The obvious disadvantage with this passive emission reduction programme is that only the technology, that is, the emission per driven kilometre, is controlled. If cars are driven a lot, they can generate as much emission as without the regulation.

The introduction of LEZs is based on a labelling system for vehicles which denotes their compliance or non-compliance with EU emission standards. Although the WHO considers these emission standards far too lax (Bowers, 2006), this system has been in place in Germany since 2007. With these labels ('Umweltplakette' or 'Feinstaubplakette') all cities in Germany can introduce conform low emission zones (Erdmenger *et al.*, 2010). Four emission categories have been defined. The first category does not receive a label, but emission categories two, three and four are linked to red, yellow and green labels respectively. Vehicle owners have to fit their cars with a label corresponding to the vehicle's emission standard in order to drive legally within the LEZ. If the necessary level to obtain a certain emission label is not reached by construction, particle filters have to be retrofitted. Enforcement is made visually by police control; a cheap but not the best enforcement mechanism since visual inspection by individuals is faulty and cannot be done in every conceivable part of the zone. Leakage is to be expected.

There is no general fee for purchasing the labels – local municipalities can decide themselves how high administrative costs for handing out the badges are. Usually prices are somewhere around six Euro (Umweltplakette, 2011). Therefore one can by no means talk about shifting costs from society to the individual polluter level.

The zone itself follows the layout of Berlin's urban railway ring (Figure 2). It was implemented gradually: in a first step in January 2008 a ban was put on cars without a label, i.e. vehicles needed to have at least the red label in order to legally enter the marked zone. In January 2010, the ban was extended to vehicles with a red or yellow label, i.e. effectively only cars with a green label are allowed to enter the LEZ.

Figure 2: Map of Berlin, the environmental zone and the monitoring stations (http://www.stadtentwicklung.berlin.de/umwelt/luftqualitaet/de/luftreinhalteplan/download/Umweltzone_Beikarten_1-10.pdf). [3]



4 Evaluation of Effectiveness of Traffic Planning Measures

In both cities environmental impact analyses have been conducted by authorities close to the government (Lutz & Rauterberg-Wulff, 2009; SLB-Analys, 2010). Both of them include only a short period after the introduction of the policy measures and mention this as a major problem of the analysis. The reports themselves admit to the fact that it is necessary to evaluate several years of measured data series of pollutant concentrations in order to draw statistically valuable conclusions about the effectiveness of a measurement on emissions, taking into account the interplay between emissions and other environmental influences that lead to the measured immission data (Lutz & Rauterberg-Wulff, 2009). Neither of them is very clear on their methodologies or includes controls of pollutant development in the surrounding areas.

A more sound comparison of pollutant concentrations is presented here. A valuation approach, which takes into account public acceptance as well as overall satisfaction in daily life, is suggested in form of the life satisfaction approach to environmental valuation.

[3] The red line denotes the border of the low emission zone. The numbers refer to a different context and can be ignored.

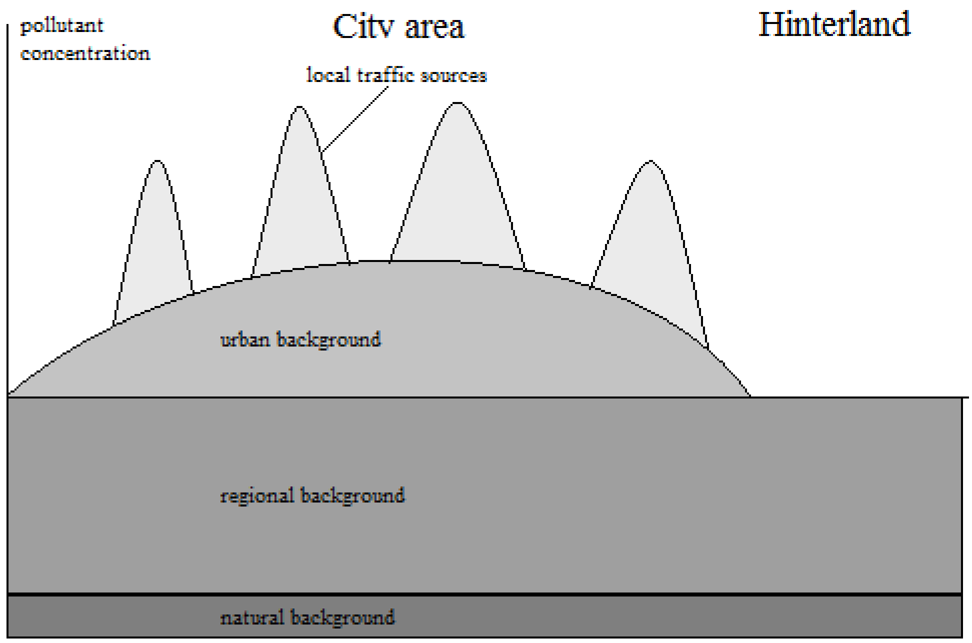
4.1 Evaluation Methods

4.1.1 Pollutant Concentrations: Study Design

This study design follows the methodology used by Atkinson et al. (2009) for evaluating the impact of congestion charging zone on ambient air pollution in London. A comparison of road-side air quality *pre* and *post* the introduction of the policy scheme is conducted. This development is compared to the development of pollutant concentrations over the same period in urban background. In addition, pollutant concentrations measured within the policy zone, the treatment zone are compared with measurements taken in areas that are not directly affected by the zone, i.e. control zone which is several kilometres away from the core of the zone (Atkinson, et al., 2009). The design implies both temporal and spatial control of time trends in air pollutant development since the control area accounts for regional background pollutant concentration which is equal for both treatment and control area. This is done in order to identify the local traffic component and separate it from regional pollutant sources. Any differences in temporal changes between zones could be attributed to the policy, if these were the only traffic measure implemented during the observed period. Comparing the trends, any changes in pollutant concentration in the treatment area that are not accompanied by changes in the control area after the introduction of the policy in the treatment area are related to the policy. A necessary assumption is that, in the absence of any policy treatment, the treatment zone would have developed similar to the control zone. For a graphic demonstration of this see Figure 3.

This approach corresponds to a Difference-in-Difference analysis. With a larger number of monitoring stations econometric regressions can be conducted. But with only two to sixteen available monitoring stations for each pollutant and large gaps in the time series, a more qualitative description of the data will have to suffice.

Figure 3: Schematic of air pollutant concentration (adapted from Lutz & Rauterberg-Wulff, 2009).



4.1.2 Life Satisfaction Approach to Environmental Quality

The common economics approach that, all else equal, more is always better is challenged by happiness research. It is argued that once we have enough to be comfortable (in terms of consumption goods and services), consuming more has other negative external effects of which people are conscious. Combined, they seem to outweigh the positive effect of consuming more. Fundamentally, negative externalities that accrue with over-consumption concern environmental externalities. Increasing road traffic is not better because of the negative externalities it produces. The research question asked by the sub-discipline is how pollution affects human well-being (Welsch, 2006). MacKerron and Mourato (2009) suggest that we derive life satisfaction from environmental quality but become sad under environmental degradation. These negative effects of pollution on life satisfaction are reason enough for controlling pollution.

Welsch's (2009) life satisfaction approach to environmental valuation offers a great opportunity to value the improvement of air quality according to how people concerned value air quality. Reported well-being can be used as a proxy for the utility derived from air quality and also capture the influence of environmental conditions of which the surveyed individuals themselves are not aware. Crudely, this can be done on a cross-national level. This is what Welsch (2006) did. He econometrically related national happiness as a dependant variable to environmental conditions and average national income.

From such a regression, it can be determined how much people are willing to pay to get rid of a certain amount of a pollutant, i.e. a "monetary valuation of environmental conditions" (Welsch, 2009). In terms of externalities, this can be interpreted as the subjective valuation of pollution externalities, irrespective of the actual costs they cause. Taking into account measured pollutant concentrations, the change in life satisfaction and 'money saved' resulting from changing pollutant concentrations can be used in the evaluation of urban transport planning schemes. The advantage of this valuation is that it implicitly takes into account other measures that were included in the planning scheme as well since availability of public transport services, time spent in congested traffic, etc. are also included in overall life satisfaction.

In order to do such an analysis, it is however necessary to have micro-data of household-surveys with reported life satisfaction and income. Life satisfaction, as people's answer to a question like "how satisfied are you with your life in general?", should be denoted on a cardinal and ordinal scale such that it can be turned into a numerical scale for analytical purposes (Welsch, 2009); denoting life satisfaction for example on a scale from one (low) to four (high). Pollutant concentrations have to be measured at a comparative level of resolution. For urban traffic planning, such data needs to be made available on a very local, disaggregate spatial level. Since there is already a significant relationship between life satisfaction and air quality at the national level, significance of air pollution for well-being on a local level is expected to be even higher and more decisive. This presents a good statistical chance to exploit data for environmental traffic planning purposes and for political objectives to gain public support for policies with proven effects on life satisfaction.

4.2 Evaluation of Air Quality Development in Stockholm and Berlin

Average pollutant concentrations were calculated for charging hours and non-charging hours[4] in Stockholm. Since the LEZ does not differentiate between hours of the day, 24-hour averages were calculated for Berlin. These values were then averaged over the pre- and post-scheme periods, respectively. Pollutant concentrations represent the negative externalities from urban road traffic. Therefore, the change in pollutant concentrations represents the effectiveness of the policy scheme in influencing the production of externalities.

In order to make any assertions about the policy effect, the induced changes in pollutant concentrations have to be persistent over time. Single observations or short observation periods might be subject to specific weather conditions or other seasonal variations (unusual, 'extreme' weather patterns or holiday seasons). Averaging over two (four) years before and five (four) years after the introduction of the policy scheme in Stockholm (Berlin) balances these factors and "minimises any potential bias arising from these unusual conditions that may not have already been accounted for by the temporal-spatial study design" (Atkinson R. W., 2009). Additionally, the temporal-spatial comparison implies that control and treatment zones are subject to the same meteorological conditions. Therefore it is not strictly necessary to control for weather.

Additionally, numbers of annual exceedances of maximum permissible values given by EU directives were calculated in order to see whether the number of exceedances was reduced by the policies.

4.2.1 Functional Chain

In order to explain the origin of the data, a short explanation of the movement of pollutants through the atmosphere seems expedient. The pollutants that are emitted into the lower atmosphere by traffic or industries are dispersed into the wider atmosphere. This transmission depends on meteorological factors such as wind and rain: strong winds aid in the dispersion of pollutants, while rain collects pollutants and accumulates them closer to the ground and to the monitoring stations. Thus, emission puts pressure on the environment since the pollutants concentrate in the air, but also in the water, the soil and the biosphere. Depending on pollutant concentration, they can have adverse effects on environment and health.

Emission data of vehicles can only be calculated if emission factors of the different vehicle technologies and the number of vehicles of each technology counted in a respective zone are known. Emission factors are determined on engine test stations under laboratory conditions. These normed emission factors do not coincide with actual vehicle emissions under road traffic conditions. Partly, real emissions deviate considerably, depending on "speed, degradation of technology, fuel characteristics, vehicle age and vehicle size" (Prost & van Dender, 2001). For nitric oxides it has been shown that actual emissions are much higher than determined in test cycles (Bowers, 2006). That the values are nevertheless often used to calculate emission is problematic since it severely understates the amount of pollutants the environment is subjected to. Therefore, an argument against the calculation of vehicle emission and deduction of air quality changes is that these calculations are unreliable and subject to a substantial number of assumptions.

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[4] For calculation purposes, charging hours have been moved to comprise times from 7-19 (instead of 6.30-18.30) to adjust for data of pollutant concentrations which are available on an hourly basis.

Immission data is the actually measured data at monitoring stations. It is therefore data that is subject to sundry impact factors apart from vehicle emission. As a detriment the relationship between emission changes and changes in measured air pollutant concentrations is often not direct, due to the fact that a complex chemistry lies behind the formation of measured pollutants (Transport and Travel Research Ltd., 2006).

An underlying assumption of the analysis is that in inner cities, especially in the two chosen capitals, a major part of air pollutants are emitted by motorised vehicles. That this is a valid assumption is confirmed by Stockholm's air quality monitoring operator (SLB-Analys, 2010). According to the proceedings of Stockholmsförhandlingen (2007) emissions of greenhouse gases have become the overshadowing environmental problem and particularly the transport sector is responsible for 30% of national emissions. Wichman (2008) confirms that the largest fraction of toxic particles in cities comes from road traffic in German cities as well, and particularly from diesel vehicles. Lutz and Rauterberg-Wulff (2009) quantify the road traffic contribution in Berlin with 40% for particulate matter and 80% for nitrogen dioxide. Neither Stockholm nor Berlin are centres of industrial production (and emission), both cities' economies rely on services.

4.2.2 Sources

Several specific pollutants are of interest here. The choice of pollutants is made based on their harmfulness for human health and the environment and on their measurement at the measurement stations: Nitric oxides (NO_x) and nitrogen dioxide (NO_2), particulate matter of ≤10µm in size (PM_{10}) and of ≤2.5µm in size ($PM_{2.5}$), and ozone (O_3). It has meanwhile been shown that $PM_{2.5}$ particles and smaller ones of a diameter of less than 1µm are more dangerous for health, but the data for these particles is scarcely available so far; they have only recently been measured and not on a wide scale.

One of the EU level directives is a set of maximum permissible levels for several pollutant concentrations in the air. Maximum permissible levels are presented in Table 3. Exceedance of these levels constitutes a breach of law and forces local governments to take preventive actions.

Table 3: Maximum permissible levels of selected pollutants (European Community, 2008)

Pollutant	**Limit Value Objective**	**Averaging Period**	**Limit Value µg/m^3**	
NO_2	Protection of human health	1 hour	200	Not to be exceeded more than 18 times in a calendar year
NO_2	Protection of human health	calendar year	40	Annual mean
NO_x	Protection of ecosystems	calendar year	30	Annual mean
PM_{10}	Protection of human health	24 hours	50	Not to be exceeded more than 35 times in a calendar year
PM_{10}	Protection of human health	calendar year	40	Annual mean
O_3	Protection of human health	8 hours	120	not to be exceeded more than 25 days per calendar year averaged over 3 years

Table 4: Measurement stations in Stockholm, pollutants measured and starting date[5] of measurement (Data obtained from Stockholms och Uppsala Läns Luftvårdsförbundet, 2012)

#	Street Name	Site description	in CCZ	NO_2	NO_x	PM_{10}	$PM_{2.5}$	O_3
01	Horngatan	Road	X	2004	2004	2004	2004	03/2008
02	Torkel Knutssonsgatan	urban background	X	2004	2004	2004	2004	2004
03	Folkungagatan	Road	X	12/2009	12/2009	12/2009	12/2009	
04	Essingeleden	Road	X	02/2005	02/2005	02/2005	02/2005	
05	Norrlandsgatan	Road	X	12/2004	02/2005	02/2004		
06	Sveavägen	Road	X	2004	2004	08/2005	08/2005	
07	E4 Sollentuna	Road				03/2007		
08	Södertälje	Road				11/2006		
09	Norr Malma	rural background		2004	2004	06/2005	06/2005	2004
10	Alby	rural background		2004				2004
11	Uppsala	Road		12/2008	12/2008	07/2007		

Air quality data for Stockholm and the surrounding area is retrieved from *Stockholms och Uppsala Läns Luftvårdsförbundet*. The monitoring network comprises 12 relevant measurement stations for air quality, six inside the congestion charging zone and six outside the CCZ, which report measured air pollutant concentration on an hourly basis. From those outside of the zone, most were added after the introduction of the CC in Stockholm and are therefore not overly useful in the analysis. Those situated in the CCZ are road side stations, apart from station number 02 that measures urban background pollution. For a detailed composition of the stations see Table 4.

Daily air quality data for Berlin has kindly been provided by the Senate Department for Urban Development and the Environment of Berlin. It was collected by the monitoring network BLUME (Berliner Luftgüte-Messnetz[6]). The network comprises 16 monitoring sites, eight of which are situated within the LEZ and eight of which outside of the LEZ. All stations within the low emission zone are road side stations and subject to frequent road traffic. Another two road side stations are situated outside of the low emission zone and six of the stations that are not within the low emission zone are urban periphery, i.e. is they are characterised by residential housing areas and relatively low traffic volume. For nitrogen dioxide measurements are available from all stations but two from 2004 onwards. The same is true for particle matter of ≤10µm in size (PM_{10}), which only two measurement sites do not report. For particle matter of ≤2.5µm in size ($PM_{2.5}$) records of only one station were available; the pollutant has therefore been dropped although particularly $PM_{2.5}$ gains in importance in research because of its severe effect on human respiratory systems. All other pollutants are measured at a selection of stations with at least one inside the low emission zone and one station outside of the low emission zone. A more compact summary of the stations and the pollutants measured can be found in Table 5.

[5] Starting date of the year given is January 1, unless differently specified.
[6] Transl.: Berlin air quality monitoring network

Table 5: Measurement stations in Berlin, pollutants measured and starting date[7] of measurement (Data obtained from Senate Department for Urban Development and the Environment of Berlin, 2012)

#	Street Name	Description	in LEZ	NO_2	NO_x	PM_{10}	O_3
01	Silbersteinstraße	Road	X	2004	2004	2005	
02	Hardenbergplatz	Road	X	2005	2006	2005	
03	Mitte Brückenstraße	Road	X	2004		2004	
04	Amtsgericht Neukölln	Road	X	2004		2005	
05	Frankfurter Allee	Road	X	2004	2004	2004	
06	Nansenstraße	Road	X	2004		2004	2004
07	Belziger Straße	Road	X	2004		2004	
08	Amrumer Straße	Road	X	2004		2004	2004
09	Mariendorfer Damm	Road		2008		2008	
10	Schildhornstraße	Road		2004		2004	
11	Grunewald	urban background		2004		2004	2004
12	Schichauweg	urban background		2004		2004	2004
13	Frohnau	urban background		2004	2006		2004
14	Buch	urban background		2004		2004	2004
15	Karlshorst	urban background		2004			
16	Müggelsee	urban background		2004		2004	2004

5 Discussion of Policy Effects

The policy effects will be discussed from several points of view: the measured change in air pollutant concentrations and possible reasons for that. Air quality changes are then taken up in showing how the life satisfaction approach can be used to analyse and compare policy effects on environmental externalities and to gain public support for policy measures.

5.1 Development of Air Pollutant Concentrations

The comparison is limited in that for some pollutants only one or even no measurement sites are available as roadside control or background control. Yet, even with the available data, it is evident that both the CCS and the LEZ have a reducing effect on pollutant concentrations (Table 6). Even controlling for background and control zone development of particle matter, the decrease in pollutant concentrations is relatively larger in the treatment zone. For nitrogen oxides (including nitrogen dioxide), the picture is less clear. Its chemical creation is subject to a more complex process that is not as strongly influenced by local vehicle emissions. The decrease at roadside stations in the treatment zone (-10.9 per cent in Stockholm, -6.5 per cent

[7] Starting date of the year given is always January 1.

in Berlin) is counteracted by an even higher decrease in urban background concentration (Stockholm, -15 per cent) or roadside concentrations in the control zone (Berlin, -26 per cent), which means that according to the model in Figure 3 the local traffic contribution to nitrogen oxides increased in real terms. Precisely the opposite picture ensues for PM_{10}. Concentrations reduced by 14 per cent in the CCZ while they reduced only by seven per cent in the surrounding control area and by even less in the background. In Berlin, roadside concentrations went down by 5.4 per cent in the LEZ and by four per cent in the control zone, leaving us with a net effect of more than one per cent. Since data on ozone is scarce (there were no monitoring stations measuring ozone in the congestion charging zone), it can only be stated that concentrations in urban background decreased by three per cent. In Berlin, in-zone concentrations decreased by five per cent.

Table 6: Mean changes before and after scheme implementation, Stockholm and Berlin (pollutant concentrations in µg/m³).

		Stockholm			**Berlin**		
Pollut-ant	**Characteristics of averaged stations**	**ø 2004-2005**	**ø 2006-2010**	**% change**	**ø 2004-2007**	**ø 2008-2011**	**% change**
NO_x	Roadside in TZ[8]	103.57	92.28	-10.91	101.13	94.53	-6.53
	Roadside in CZ[9]				56.88	42.09	-26.00
	Background in TZ	20.65	17.45	-15.47			
	Background in CZ	3.57	3.42	-4.26	3.43	3.87	12.90
NO_2	Roadside in TZ	43.15	41.43	-3.99	40.68	40.70	0.07
	Roadside in CZ				57.21	51.91	-9.26
	Background in TZ	16.13	13.96	-13.42			
	Background in CZ	3.22	3.03	-5.85	16.13	15.39	-4.62
PM_{10}	Roadside in TZ	34.43	29.75	-13.59	29.65	28.04	-5.44
	Roadside in CZ	15.64	14.54	-7.04	33.39	32.08	-3.94
	Background in TZ		22.94				
	Background in CZ	9.45	8.89	-6.00	22.60	21.47	-5.02
$PM_{2.5}$	Roadside in TZ	13.24	9.69	-26.83			
	Roadside in CZ						
	Background in TZ	9.30	7.11	-23.61			
	Background in CZ	6.44	5.10	-20.80			
O_3	Roadside in TZ		26.20		8.64	8.16	-5.59
	Background in TZ	52.14	50.58	-3.00			
	Background in CZ	61.17	54.52	-10.87	2.95	3.51	18.71

Air quality impact analyses have been conducted short term for both Berlin and Stockholm, for the latter mainly on the trial period, but not on the permanent installation of the charging scheme (Lutz & Rauterberg-Wulff, 2009; SLB-Analys, 2010). Reports so far have concentrated on traffic volume impact and economic impacts on the city. The reports themselves admit to the fact that it is necessary to evaluate several years of measured data series of pollutant concentrations in order to draw statistically valuable conclusions about the

[8] TZ: Treatment Zone (Zone in which policy was implemented)
[9] CZ: Control Zone (Zone around Treatment Zone in which policy was not implemented)

effectiveness of a measurement on emissions, taking into account the interplay between emissions and other environmental influences that lead to the measured immission data. The SLB report uses only pollutant concentrations from 6am to 7pm and only on weekdays because only those times are subject to the tax. It calculates the contribution of road traffic to pollutant concentration by subtracting background measurements on rooftop level from measurements at the monitoring stations on street level. If however the total Stockholm traffic planning package and its behavioural inducements want to be analysed, all 24 hours have to be included to take into account adjustments that travellers made to their trip timing to circumvent the charge.

The analysis of SLB-analys finds that particulate matter concentrations have stayed almost the same due to the continuous use of studded tyres. But they remark that PM_{10} concentrations also depend highly on meteorological conditions which were rather favourable for high concentrations during 2007 and 2008. This compares to my results which show an approximated six per cent reduction attributable to roadside traffic in the treatment zone in Stockholm and a negligible reduction in Berlin.

Stockholm results put forward that congestion charges alone cannot account for the temporal changes of pollutant concentrations. Rather, total urban traffic management packages may account for them, because the reduction in air pollutants was noticeable after charging hours as well (Table 7). Since monitoring stations outside of the CCZ reflect to a certain extent similar temporal changes as within the charging zone, the changes (decreases in pollutant concentrations) might either be attributable to other, complementary actions of traffic management that were active beyond the charging zone, or the charges led to changes that affected measures in background and outside the zone as well. Nevertheless, comparing relative reductions of pollutant concentrations between Berlin and Stockholm seems to indicate that the CCS is more successful when it comes to air pollution. In the treatment zone, pollutants decreased by a higher percentage in Stockholm than they did in Berlin. A reason for this might be that the Stockholm CCS was introduced almost two years earlier than the LEZ and that during that time Stockholm's residents had longer time to adjust their behaviour and replace the vehicle park, a change that can still occur in Berlin during the following years. Or the congestion charging scheme in combination with its package components is a more potent tool to decrease air pollution from road traffic. After all, it affects not only the number of vehicles entering the zone, but it also stimulates alternative transport modes, while the LEZ only affects the latter, and this merely by way of one channel, i.e. vehicle banning.

Table 7: Yearly air concentrations of pollutants in Stockholm[i], by monitoring characteristic (pollutant concentrations in µg/m³).

Pollut -ant		Characteristics of averaged stations	2004	2005	% change	ø 2004-2005	2006	% change	2007	% change	2008	% change	2009	% change	2010	% change
NO_x	during charging hours	roadside	109.27	108.47	-0.73	108.87	101.44	-6.83	101.81	-6.49	96.33	-11.52	93.11	-14.48	98.06	-9.93
		urban background	22.81	21.03	-7.79	21.92	22.07	0.67	18.06	-17.58	15.97	-27.15	16.55	-24.47	19.98	-8.83
		rural background	3.50	3.87	10.38	3.68	4.71	27.75	3.33	-9.57	2.83	-23.26	3.01	-18.28	3.63	-1.43
	after charging hours	roadside	73.59	70.61	-4.05	72.10	65.81	-8.72	62.45	-13.39	59.27	-17.79	58.28	-19.17	59.95	-16.86
		urban background	15.93	14.51	-8.92	15.22	15.44	1.44	12.25	-19.50	11.14	-26.84	11.37	-25.29	13.21	-13.21
		rural background	3.07	3.47	12.90	3.27	4.32	31.97	3.04	-6.95	2.60	-20.58	2.72	-16.88	3.32	1.41
NO_2	during charging hours	roadside	43.73	43.49	-0.56	43.61	42.76	-1.96	42.03	-3.62	41.38	-5.11	44.07	1.04	43.89	0.65
		urban background	17.65	15.96	-9.62	16.80	17.06	1.50	14.09	-16.16	13.14	-21.79	12.96	-22.85	15.68	-6.69
		rural background	3.16	3.46	9.51	3.31	4.21	27.43	2.99	-9.63	2.49	-24.82	2.66	-19.63	3.12	-5.76
	after charging hours	roadside	36.76	35.40	-3.70	36.08	34.01	-5.73	31.63	-12.34	30.64	-15.08	29.59	-17.98	32.11	-10.99
		urban background	14.08	12.58	-10.63	13.33	13.47	1.09	10.48	-21.35	9.93	-25.47	10.06	-24.49	11.78	-11.60
		rural background	2.85	3.16	11.08	3.00	3.95	31.42	2.77	-7.72	2.32	-22.73	2.48	-17.37	2.89	-3.78
PM_{10}	during charging hours	roadside	37.45	34.37	-8.22	35.91	35.66	-0.71	34.53	-3.84	32.01	-10.88	27.07	-24.61	25.94	-27.77
		urban background					21.99		26.40	20.06	27.78	26.35	24.24	10.23	20.20	-8.15
		roadside, outside of CCZ	15.58	16.72	7.25	16.15	17.09	5.84	15.05	-6.78	14.82	-8.22	14.07	-12.88	13.55	-16.12
		rural background		9.66		9.66	10.94	13.26	9.15	-5.27	8.35	-13.55	7.20	-25.47	8.90	-7.91
	after charging hours	roadside	29.08	25.78	-11.34	27.43	27.05	-1.38	24.87	-9.34	23.76	-13.37	20.16	-26.50	20.32	-25.90
		urban background					16.36		19.88	21.54	20.48	3.01	17.35	-15.25	16.21	-6.58
		roadside, outside of CCZ	13.55	13.82	2.05	13.69	14.87	8.63	12.61	-7.90	12.45	-9.06	12.03	-12.10	11.93	-12.86
		rural background		9.07		9.07	10.54	16.10	8.81	-2.89	8.22	-9.44	7.15	-21.23	8.95	-1.38

Pollut-ant		Characteristics of averaged stations	2004	2005	% change	ø 2004-2005	2006	% change	2007	% change	2008	% change	2009	% change	2010	% change
$PM_{2.5}$	during charging hours	roadside	14.81	12.33	-16.77	13.57	12.68	-6.52	10.03	-26.07	9.79	-27.86	8.74	-35.59	8.30	-38.85
		urban background	8.79	9.98	13.50	9.39	9.45	0.70	7.01	-25.28	6.58	-29.92	6.09	-35.10	6.28	-33.15
		rural background		6.65		6.65	7.10	6.72	4.90	-26.35	4.26	-35.87	4.90	-26.35	4.30	-35.30
	after charging hours	roadside	12.35	10.35	-16.19	11.35	11.12	-2.01	8.04	-29.14	8.04	-29.15	7.07	-37.68	7.49	-34.02
		urban background	8.85	9.07	2.50	8.96	9.31	3.92	6.75	-24.71	6.45	-28.04	6.01	-32.93	6.34	-29.30
		rural background		6.22		6.22	6.91	11.23	4.79	-22.98	4.31	-30.65	4.89	-21.36	4.44	-28.58
O_3	during charging hours	roadside									35.51		34.93		32.75	
		urban background	51.35	51.64	0.58	51.50	54.42	5.67	50.44	-2.06	50.96	-1.04	47.59	-7.58	49.06	-4.73
		rural background	58.76	63.95	8.83	61.35	63.23	3.06	52.25	-14.85	53.36	-13.03	53.13	-13.40	53.11	-13.43
	after charging hours	roadside									39.56		38.95		37.00	
		urban background	54.05	53.71	-0.64	53.88	55.57	3.14	51.70	-4.05	51.34	-4.72	47.51	-11.83	50.61	-6.07
		rural background	57.65	61.65	6.95	59.65	60.02	0.63	51.10	-14.34	51.47	-13.72	51.08	-14.37	50.66	-15.08

[i] Shadowed cells mark negative relative changes compared to base year.

Table 8: Annual Number of Exceedances in Stockholm.

	Station	2004	2005	2006	2007	2008	2009	2010
Hourly NO_2 exceedances	01				2			
	02				2			
	03						1	
	04						1	
	05			1				3
	06		2		2	1		
	09		2		2	1		
	10		1			4	4	
	11		1			4	4	
Daily PM_{10} exceedances	01	79	80	65	73	76	67	48
	02	2	1	6	5	2	1	1
	03		60	73	34	62	58	39
	05	59	67	74	57	49	30	27
	06			67	44	55	33	29
	07				12	21	14	12
	08			2	40	54	43	31
	09			4	1			
	11				10	54	44	29
Exceedances of 8-hour average of O_3	02	7		60		8	9	5
	09	68	16	91	1	7	12	19
	10		23	70		2		

At all stations that measured nitrogen dioxide in Stockholm, a negligible amount of hourly exceedances of the maximum value were registered, never exceeding a total of 10µg/m^3 within one calendar year. Exceedances of PM_{10} show a decreasing trend at most of those stations after the introduction of CC. The exception is the year 2008, when a surge in exceedances was registered in all but two stations. At those the number of exceedances of the limiting value of ozone has a lower mean during the years 2006-2010 (Table 8). Yearly limiting values were never exceeded.

Data on Berlin was only detailed enough for PM_{10} to calculate. The maximum yearly average of 40µg/m³ was never exceeded, but exceedances of the daily maximum level of 50µg/m³ did occur (Table 9). The exceedances were lower at all stations from 2007 to 2009, only to increase again one year after the introduction of the LEZ. The development of extreme values does not give conclusive evidence on the effectiveness of the LEZ.

Summarising air quality developments, pollutant concentrations decreased more significantly in Stockholm than in Berlin. Congestion Charges appear to be a better tool to achieve air quality targets, or low emission zones needs some more years for more noticeable effect.

Table 9: Annual Number of Exceedances in Berlin (PM_{10} only).

Station	2004	2005	2006	2007	2008	2009	2010	2011
01		75	68	32	23	35	52	55
02		43	50	18	13	24	38	38
03	21	28	63	15	10	19	33	33
04		61	55	24	10	23	41	41
05	43	73	72	29	24	40	56	48
06	20	32	38	17	10	23	39	32
07	19	22	23	13	10	17	35	
08	18	21	27	14	9	15	29	35
09						73	57	47
10	40	62	55	24	15	31	48	42
11	5	12	21	10	5	11	23	26
12	15	21	22	12	2	13	29	
14	15	18	28	11	6	9	23	26
16	8	15	22	10	7	7	28	27

5.2 Other Mechanisms Influencing Air Quality in Inner-cities

In the case of Stockholm, it is problematic to find causal relationships between changes in pollutant concentrations and introduction of the treatment zones since the schemes have been accompanied by other complementary measures within a comprehensive urban planning package. The discussion whether the measured effect on air quality is really attributable to the introduction of a treatment zone seems hardly to be the right question to ponder. Especially in the case of user charges it is elementary to complement the charges with further (visible and clearly charge-related) measures in order to secure public support. Erdmenger et. al (2010) established the hypothesis that “a congestion charge implemented without being integrated into a raft of other measures will not be able to deliver environmental and transport improvements”. If public transport services are not available, the highest charge is meaningless if people are not offered an alternative mode to get to work. So if it is the aim of a policy to get drivers off the road and incentivise them to substitute with other modes they need to include complementary measures into the policy package like widening public transport services, constructing bicycle and pedestrian paths, and actively promote environmental-friendly driving behaviour as done to large extents in Stockholm.

At least initially (until August 2012), the CCS goes along with an exemption of alternative-fuel, hybrid, and electric vehicles. Parallel to the introduction of the CC, sales of clean vehicles were promoted in Sweden. Free residential parking for clean vehicles was introduced already in 1997 and park-and-ride facilities expanded as an element of the CCS. Complementary actions also include policy incentives and tax reductions for the purchase of low-emission vehicles, not only for households but also for public (busses, metro) and private sector (taxi, transport companies, delivery services) vehicle parks (Stockholmsförhandlingen, 2007). In both countries, there were subsidies to buy low-energy vehicles during the time the environmental planning schemes were introduced.

This and the increased market for alternative vehicles resulted in added sales of clean vehicles in Stockholm. More variations of the alternative fuel vehicles are on offer, and they are more present due to the on-going debate about their fuel-efficiency and their future prospects. The Euro emission standards act as supply-side measures for the alternative fuel vehicle market. Transition to less-polluting vehicles is aided by fuel taxes that are aimed at influencing household's choice of vehicle type (Hensher, 2008)**.**

Both in Sweden and in Germany, vehicle taxes are carbon based which implies a tax advantage for low-energy vehicles. Vehicle taxes for newly registered vehicles are calculated according to CO_2 emissions (vehicle's values from test cycles). If they are below 120gr/km (110 gr/km since 2012), no additional tax for CO_2 has to be paid. This further encouraged purchase of low-energy vehicles and contributes to a technology change of the vehicle fleet with a potential effect on air pollution concentration. This, as much as the charge and the reduction in traffic itself, reduced emission and therefore air pollution.

In Figure 4 and Figure 5 vehicle statistics of newly registered vehicles can be found for Stockholm[10]. Registrations of alternative fuel vehicles[11] made up a larger part in total new registrations in Stockholm city than it did in Stockholm county (great Stockholm area), even though new registrations of alternative vehicles increased from 2007 to 2008 in both areas. Correspondingly, the share of alternative passenger cars in use increased steeply during 2006-2009 both in the city (from two to almost fifteen per cent) and its surroundings (from two to ten per cent). The CC and exemptions for alternative vehicles seem to have had a larger effect in the city itself. SLB-analys (2010) holds that the "exemption from congestion tax has been the single most important incentive to getting Stockholm's residents to buy more alternative fuel vehicles. The environmental gains, which during the trial of 2006 consisted primarily of less traffic volume, have thereby been replaced by gains due to altered and cleaner vehicle fleet".

Table 10 for Berlin shows a reduction of concentrations already in 2007, one year before the introduction of the LEZ. This could be an early effect of the tax incentives and financial supports that set in even before the zone was introduced.

An initial impact report published shortly after the trial found that the trial cut traffic volumes crossing the CC cordon significantly. This decline also includes traffic in the outskirts of Stockholm that are not situated within the charging zone and traffic during evenings after charging hours (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2010).

There were some worries about attenuation of the effect because road users get habituated to the charges and ignore them as additional costs or because new drivers replace those that were driven off the road by increased costs of transport. However, such adaptation did not take place, traffic flows stayed at a lower level. The policy may actually have changed people's behaviour and got them to discover alternative transport modes and develop new travelling habits (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2010). Traffic volumes in the year after the re-introduction in 2007 increased again slightly. However, a time series analysis conducted by the authors showed that the external factors that significantly affected traffic development in the long run include the number of people in employment, fuel prices and private cars per employed person. This suggests that congestion charges were not a determining factor for traffic volume in the tested series and that over time the measured effect of the CC will attenuate after all.

[10] Numbers have been retrieved from Statistics Sweden (Statistiska Centralbyrån).

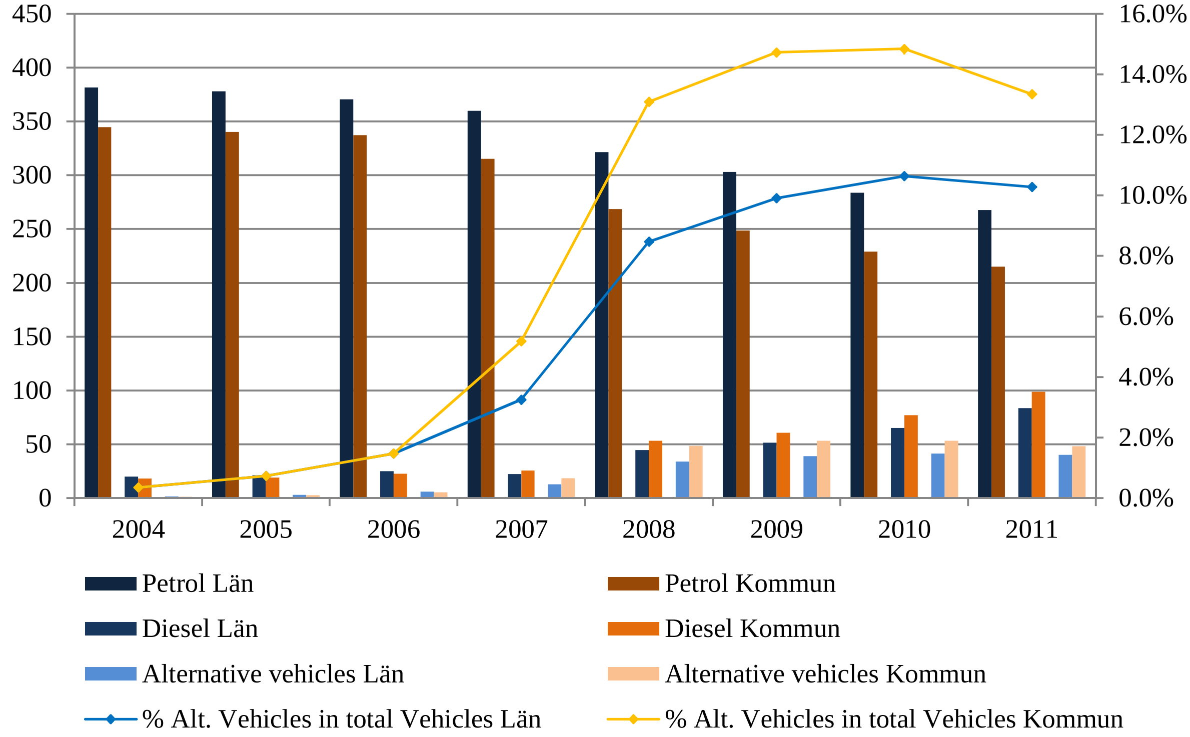
[11] Alternative fuel vehicles include vehicles running on gas, ethanol, electricity or are hybrids.

Table 10: Yearly Means in Berlin (pollutant concentrations in µg/m³).

Pollut-ant	Characteristics of averaged stations	2004	2005	% change	2006	% change	2007	% change	ø 2004-2007	2008	% change	2009	% change	2010	% change	2011	% change	ø 2008-2011	% change
NO	roadside, in LEZ	32.61	27.45	-15.83	30.33	-6.97	26.15	-19.80	29.13	26.43	-9.27	28.30	-2.86	25.89	-11.14	28.30	-2.86	27.23	-6.53
	roadside, not in LEZ	65.73	68.65	4.44	52.26	-20.49	40.86	-37.84	56.88	37.77	-33.60	44.81	-21.21	41.04	-27.84	44.74	-21.34	42.09	-26.00
	background[i]	3.94	3.24	-17.85	3.82	-3.22	2.72	-30.92	3.43	3.00	-12.44	4.43	29.25	3.88	13.20	4.17	21.59	3.87	12.90
NO_2	roadside, in LEZ	37.16	38.95	4.83	45.64	22.84	40.96	10.24	40.68	39.50	-2.89	41.10	1.04	40.92	0.59	41.30	1.53	40.70	0.07
	roadside, not in LEZ	55.59	59.02	6.17	60.91	9.58	53.33	-4.06	57.21	49.50	-13.48	53.81	-5.95	51.84	-9.39	52.50	-8.23	51.91	-9.26
	background[i]	15.86	14.87	-6.26	18.16	14.46	15.64	-1.39	16.13	15.25	-5.49	15.36	-4.77	15.80	-2.06	15.14	-6.16	15.39	-4.62
O_3	roadside, in LEZ	10.11	8.63	-14.63	8.86	-12.38	6.95	-31.23	8.64	7.29	-15.56	8.66	0.26	7.43	-14.00	9.24	6.93	8.16	-5.59
	background[i]	3.43	2.73	-20.41	3.32	-3.14	2.34	-31.71	2.95	2.55	-13.77	4.14	40.09	3.57	20.97	3.77	27.56	3.51	18.71
PM_{10}	roadside, in LEZ	27.02	31.36	16.08	34.03	25.93	26.20	-3.02	29.65	26.30	-11.30	28.37	-4.34	29.47	-0.63	28.03	-5.48	28.04	-5.44
	roadside, not in LEZ	33.67	35.86	6.50	36.47	8.30	27.56	-18.17	33.39	28.30	-15.24	33.97	1.72	35.52	6.37	30.52	-8.60	32.08	-3.94
	background[i]	20.59	23.12	12.26	25.63	24.46	21.06	2.26	22.60	19.25	-14.82	22.10	-2.23	23.39	3.50	21.13	-6.52	21.47	-5.02

[i] Outside of LEZ.

Figure 4: Passenger Cars in Use per Thousand Inhabitants, at the End of the Year, by Fuel (Sources: Statistiska Centralbyrån, Trafikanalysen)[12]



In Berlin, as a first step in January 2008 a ban was put on cars without a label: This already led to replacing and retrofitting vehicles (much like the trial period had an early effect before the final implementation of the CC). The modernisation excited by introducing the LEZ took effect inside as well as outside of the demarcated zone (Lutz & Rauterberg-Wulff, 2009), since many car owners that travel outside of the zone also travel inside of the zone (for instance because they live outside of the zone but commute to a place within the zone to work).

Another important source of particle emission are planes (Helmers, 2009). Significant changes of jet emission, airports and number of flights can overlay effects from CCZ and LEZ. In Berlin, the airport Tempelhof closed down in October 2008. But since emissions at higher altitudes are more widely dispersed, the closure of Tempelhof had an effect on both local and background concentrations and therefore only effects temporal but not spatial pollutant developments.

Reducing the use of studded tyres would be a big step in reducing particle concentrations in Stockholm where the use of them is still widespread throughout winter. In Germany on the other hand, it is forbidden studded tyres.

To sum up, the changes in the vehicle fleet induced by urban planning schemes explain a major part of decreases in Berlin. In Stockholm, cleaner vehicle fleet, less congestion and successful promotion of alternative transport modes, contribute to better air quality.

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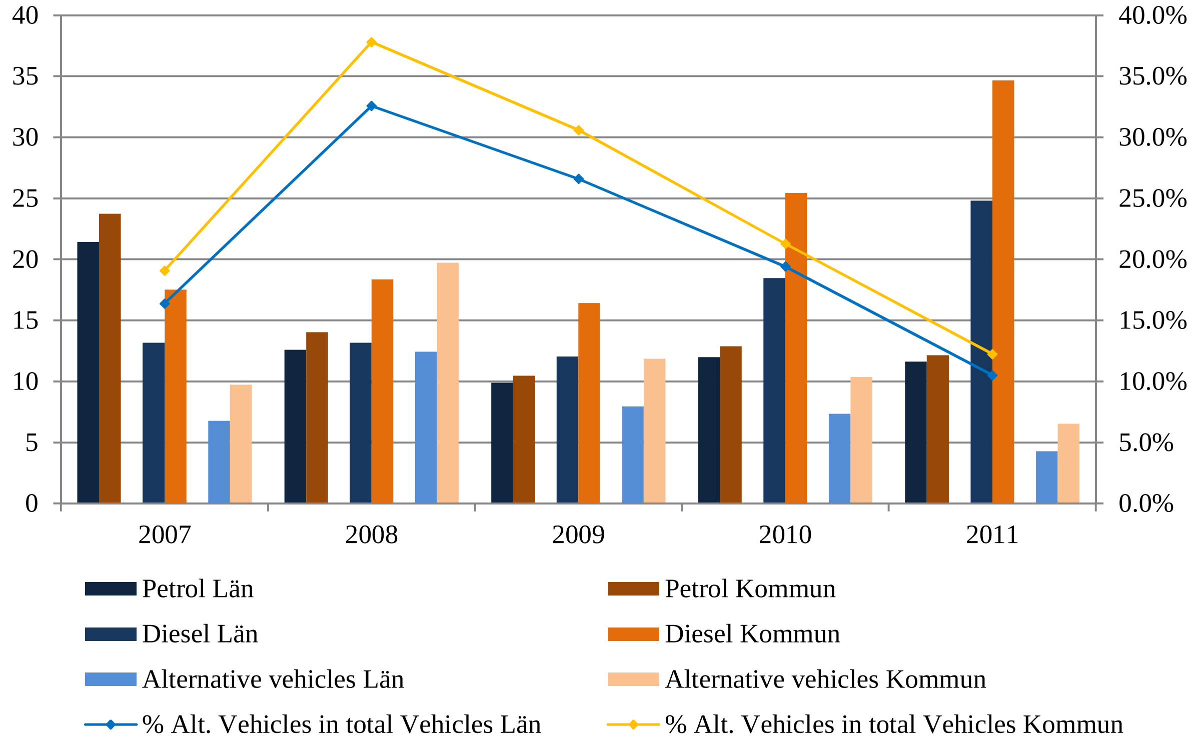
[12] The percentage of alternative vehicles in total vehicles for 2004-2006 is estimated from aggregate Swedish vehicle statistics.

Figure 5: New Vehicle Registrations per Thousand Inhabitants, at the End of the Year, by Fuel (Sources: Statistiska Centralbyrån, Trafikanalysen)



5.3 Behavioural Change

Demand for road transport is often quite inelastic – residents of suburban areas need to travel to work or do shopping trips to the city. A slight cost increase does not deter this need. So, unless adaptation methods are offered (in form of changing people's minds about their preferred travel mode and timing and offering them alternative transport modes) individuals will not change their private car use dramatically (Verhoef, Nijkamp, & Rietveld, 1995). Influencing behavioural change aims at moving the demand curve – people should feel the need to use their car less often – rather than moving demand along the curve (Verhoef, Nijkamp, & Rietveld, 1995). Attitude and persuasion policies are contingent on voluntary responses of individuals; therefore, their social feasibility is high.

In a panel study on household level from 2004 to 2006, Becker (2008) elicits some of the behavioural changes that the Stockholm trial presumably affected in residents. According to Becker, if people changed their transport mode, then they switched to public transport – this happened in the whole county but more noticeably in trips that crossed the CC cordon (Becker, 2008). For distances that were formerly covered by car, going by foot or bike is not an option for most people when passing to work, home or for shopping trips. This highly supports the hypothesis that road pricing schemes can only reach environmental targets if the scheme is accompanied by other measures like the provision of public transport.

The survey elicited a minute decrease of trips by car passing the cordon during the trial, but this does not exclude that travel within the cordon and travel outside of the cordon did the same, they might still increase. The cost of the charge does not seem to completely outweigh the advantage from travelling to the inner-city by car (Becker, 2008). Therefore decreases in emissions are, if at all, attributable to replacement and change in inner-city transport behaviour not in travel to and from the city. With road users adjusting their travels after the CCS has been in place for a while, the long term effects of CCS might actually be smaller than the short term effects on pollutant emissions. On the other hand, short term effects might have less impact than long term effects since larger adjustments to the charges, for instance choice of residence or type of vehicle, might take some time to take effect. Also policies to change personal attitudes towards pollution-generating activities are ineffective in the short run but might return significant success when manifested in the long run.

Behavioural change in Berlin has not been examined – apart from the insight that traffic did not seem to be diverted to roads outside the LEZ no behavioural changes could be elicited (Lutz & Rauterberg-Wulff, 2009). Apart from the necessity to upgrade technology in order to comply with the zone's entrance requirements, there is no other element that gives individuals an incentive to change their behaviour, drive less and switch transportation mode. While congestion charges imply an additional cost for road users, LEZ do not do so. Even if the LEZ implies higher costs for the initial purchase of a new car or a particle filter, users feel like they pay in return for something, "they get some 'value for money'" (Verhoef, Nijkamp, & Rietveld, 1995).

Traffic diversion is a constant threat of place-bound urban planning schemes. If only part of a road network is tolled, then drivers might decide to redirect their trips, thereby moving externalities to other areas (Anas & Lindsey, 2011). They might merely move pollution to other areas if car owners who do not comply with emission standards decide to circumvent the zone instead of upgrading their vehicle technology. This might be the case if the low emission or congestion zone was merely a thoroughfare and alternative routes that lie outside of the environmental area lead to the destination as well. However, such thoroughfares are usually controlled by road tolls and not by environmental zones. If, on the other hand, the area that is covered by the zone is an area of its own importance or if popular destinations lie within the zone, then movement within the area has to be adjusted to more environmental-friendly vehicles or transport options.

As in the Berlin case, a concern that traffic would be moved to areas outside of the zone was dispelled in Stockholm. Instead, Stockholm travellers altered their travelling behaviour by choosing different modes and doing fewer trips as well as adjusting their departure times in order to not pay the highest charge (Anas & Lindsey, 2011).

To sum up, ideally, an urban planning scheme achieves a change in the minds of people concerning their preferred travel times and modes. In Stockholm, the policy package with increased public transport and charges that vary with vehicle type achieved this. In Berlin, an incentive towards behavioural change cannot be distinguished.

5.4 Life Satisfaction Analysis

Conducting a life satisfaction analysis of the environmental conditions in the cities could give an important insight into policy schemes' effectiveness as well as contribute to the valuation of the external cost in order to conduct a detailed cost-benefit analysis of the schemes. Welsch (2006) found a considerable monetary value of 750$ per capita for the annual reduction in nitrogen dioxide from 1990 to 1997 in European countries. Welsch and Menz (2008) find that "a 1-microgram increase in PM_{10} concentrations is equivalent to a 0.3% decrease in income".

This implies that a decrease of almost five µg/m³ in PM_{10} as experienced in Stockholm after the introduction of congestion charges corresponds to a 1.5 per cent increase in income.

Welsch's univariate framework finds that, irrespective of country and level of life satisfaction, a one per cent increase in particle matter goes along with a 0.022 per cent decrease in life satisfaction. Although in the multivariate regression that includes nitrogen, lead and income, particle matter turns insignificant due to a strong correlation with income[13], the effect of particle matter on life satisfaction is indirectly captured by coefficients of nitrogen dioxide (-0.057) and lead (-0.012); their presence is strongly correlated with the presence of particles. For approximation purposes, it is therefore justified to use the coefficient of the univariate framework.

Calculating the difference between happiness as a function of income and particle matter at the beginning and at the end of the observation period gives the change of life satisfaction as particle concentrations change[14]. Introducing average income per capita for Berlin (2009: 33000 Euro)[15] and Stockholm (2010: 33700 Euro)[16], and the means in particle concentration from Table 6 into the framework, results for both cities in similar, positive changes of life satisfaction of a magnitude of 0.06 on a satisfaction scale ranging from one to four, although they are slightly higher in Stockholm since here pollutant changes were more significant.

This is only a rough approximation of the effect of a change in particle concentrations. Adding the effects of other pollutants might result in even larger improvements on well-being. Over a longer period after scheme introductions, when improved air quality is reflected in long-term health (cf. Wichmann, 2008) and found its way into people's life satisfaction, a more detailed comparison of urban planning schemes can be conducted.

If the magnifying relationship holds true when moving from national to local analysis, then this estimation on city-level with the values calculated by Welsch is likely to underestimate the actual effect of pollution on happiness. However, while national happiness indices exist for most nations[17], there is no such thing for individual cities or households. Even if some surveys might be conducted in regular intervals in capitals, they generally do not ask for life satisfaction. So, in order to obtain more regional results with spatially more disaggregate data, it is necessary to conduct tailored and repeated surveys in cities that plan to introduce and have introduced environmental planning schemes.

The life satisfaction approach to economic evaluation can give a direct estimate of policy schemes' influence on residents' well-being or be turned into monetary valuations. This is done by looking at the elasticities between pollutants and income, i.e. how much income an individual would be willing to give up in exchange for a certain amount of pollutant reduction. It is of course controversial to attach a monetary value to happiness. On the other hand, capitalism allows us to buy almost everything – why not happiness? To some the idea of becoming happier by way of paying for environmental improvement might appeal.

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[13] An income per capita increase of one per cent is accompanied by a particle reduction of 2.5 per cent (Welsch, 2006).

[14] Δlife satisfaction=Δ V(income, particles) $=e^\wedge(0.259\log(income_1)-0.022\log(particles_1)-(0.259\log(income_1)-0.022\log(particles_0))$, where subscripts denote periods before (0) and after (1) the introduction of transport management schemes. Coefficients are taken from Welsch (2006), who holds that they are transferrable to other European countries for approximation purposes, but are by no means definitive, more detailed research and data is needed.

[15] Source: Genesis database (Statistisches Bundesamt)

[16] Source: Statistics Sweden

[17] (cf. Erasmus University Rotterdam, 2009)

Therefore the effect may be successfully communicable to gain public support: 'Cleaner air makes you happy – go buy electric cars.'

5.5 Gaining Public Acceptance and Support

Seeing as British surveys have shown that double as many road users are willing to pay more for environmental improvements than for alleviating congestion, it is surprising how public discourse and academic research focus primarily on the congestion externality of road use and potential time savings to be gained by road pricing instead of improving air quality with urban road policy measures.

Social sciences foster the idea that individuals engaging in environmentally-friendly behaviour derive well-being from, one, a "warm glow effect", i.e. the private contribution to better environmental quality makes an individual proud about their positive behaviour; and two, from the actual improvement in (public) environmental quality (Welsch, 2009). People might produce fewer externalities if they feel social pressure to contribute to environmental quality. With policy measures, this social pressure can be built up, if it does not yet exist. The best policy measure for governments to use in order to achieve social pressure is via increasing visual activities. Emission-labelled vehicles make the air quality contributions of each road user more visible and might increase social pressure for each individual to lower their contributions. This characteristic of social control implies that optimal user charges for pollution do not actually need to be as high as theoretical marginal external costs of pollution demand. If the LEZ or the charges manage to establish some kind of social norm for environmentally-friendly driving behaviour, social pressure might encourage road users to reduce car use: If everyone else switches to low-energy vehicles, individuals might feel obliged to do so as well.

Despite general awareness that environmental problems arising from car use severely threaten society's welfare[18], travel management might not be welcomed with acceptance if it implies costs and behavioural change for the individual. Jakobsson et al. (2000) note that individuals might feel restricted in their freedom by having to pay for a 'right' that has previously been free of charge. And this is although the public is the beneficiary of road pricing schemes in the form of lower external costs. Since political acceptance of road pricing schemes will only be gained with sufficient public support, gaining this support is a major challenge for policy makers. In fact, the absence of public support has been the central obstacle to implementing user charging schemes, for example, in Edinburgh, Manchester and Manhattan (Anas & Lindsey, 2011). Local businesses can form a powerful lobby against road pricing if they fear they will lose their customers. Similarly, the automobile industry is a pressure group that affects public opinion. Confronted with severe resistance, no wonder that for many years the idea of urban traffic management by charging users has remained a theoretical concept for the amusement of researchers only. But in the last two decades the concept of road pricing has come into practice, albeit slowly and under continued protest of many road users (de Palma & Lindsey, 2011).

Public acceptance of LEZs in Germany is ambiguous. Their proponents praise them while opponents keep objecting to them (Zellner, 2009; Wichmann, 2008). LEZs are controversial although they demand relatively little organisational costs and do not even go along with

[18] "Too much pressure on the environment may negatively affect long-run social welfare both through lower-quality environmental amenities and decreased environmental productivity." (Nijkamp, 1994)

direct costs to road users. Oberholzer-Gee and Weck-Hanneman (2002) argue that, in order for road management schemes to be effective, public attitudes towards market based solutions need to be taken into account. Along this rationale LEZ as proposed in Berlin should find more public support than congestion charges since there are no direct costs involved in entering the designated zone and barely any costs connected to the actual regulation: designating the boundaries of the LEZ is cheaper than setting up technological infrastructure for an ERP.

An effective way to gain public support was the trial done in Stockholm, followed by an evaluation and public vote on whether to permanently install the CCS or not. Having experienced the trial and knowing that they would have the chance to collectively decide for or against its permanent installation calms public opinion. Holding a referendum once a trial has been done is more advisable than holding a referendum before the implementation. People can get accustomed to road charges and possibly notice that their life satisfaction in total is not negatively influenced by it.

Investing into public transport services also strengthens public support. In particular, highly visible investments, rhetorically explicitly connected to the charges, are desirable since they openly show to payers of the charge where the tax was invested. In fact, in Stockholm revenues from the charge are earmarked for the improvement of local public transport (cf. Verhoef, Nijkamp, & Rietveld, 1995). The package approach put in place in Stockholm to enhance public support explicitly linked the increased public transport services and park-and-ride facilities to the charges. While the nature of LEZ as a non-pricing measure makes it alluring, the concept proves to be disadvantageous when it comes to increasing public support via increasing public spending that is covered by revenues since no revenues are raised from the policy.

For increasing public support, complementary measures should mainly aim at compensating those who loose from urban planning schemes (Oberholzer-Gee & Weck-Hannemann, 2002). Those that are forced to switch transport modes because personal transport became too costly can be compensated by offering them a broad service, possibly lower prices on public transport, and well-timed connections; those who have to buy new vehicles can be supported with a subsidy to their purchase – connected to the condition that the new vehicle has to be a low-energy vehicle.

Unfortunately, improvement of air pollution is not very pre-eminent. Charging stations and road signs[19] reminding road users when they enter the environmental zone, on the other hand, are very visible. They will keep reminding users of the costs they incur without being reminded about positive effects of these costs. LEZ road signs are omnipresent, as are electronic payment stations in Stockholm.

The Stockholm scheme appears to be economically beneficial and has crossed the cut-even point already after a few years (de Palma & Lindsey, 2011). Having a positive cost-benefit balance is always helpful in securing public acceptance. On the bright side, the LEZ, even if possibly ineffective, poses no direct costs to taxpayers.

To sum up, social feasibility of urban road management systems depends not only on cultural determinants and attitudes but also to a large degree on economic, technical and institutional feasibility. Restrictive demand side policies are likely to be met with more resistance than

[19] Road signs set up in German cities to indicate required emission labels have in fact erupted in heated discussions about wasting tax money on producing and setting up these signs instead of using it more productively to improve the infrastructure.

public promotions campaigns and indirect demand management by way of offering substitutes and supply side policies (cf. Verhoef, Nijkamp, & Rietveld, 1995).

6 Conclusion

This thesis was concerned with integrating Stockholm's congestion charging scheme and Berlin's Low Emission Zone in the theoretical literature on negative externalities in road use. It contrasts analyses of air quality effects, and discusses the need for a more profound, comparative impact analysis in order to increase public acceptance and possibly in the long term influence people's inner-city travel behaviour, and in order to facilitate replication in other cities.

In the comparison between Stockholm's congestion charges and Berlin's low emission zone, a clear winner can obviously not be determined since overall economic effects have not been included in the analysis. But when it comes to air quality effects, in both cities, mean pollutant concentrations in treatment zones decreased even when taking into account three to four years after the introduction of the traffic planning schemes. Compared to Berlin, pollutant concentrations decreased relatively more in Stockholm, which suggests reasoning that the latter is preferable when it comes to targeting improvement of air quality. This result also makes sense in that the congestion charges, including their package of measurements, address two out of three influential factors, namely number of vehicles and vehicle technology (i.e. abatement strategies), from the external cost model while low emission zones only address abatement strategies.

If failure to secure public acceptance and ineffectiveness to reach its aims prevail a transformation of the outlay of low emission zones will be necessary. Direct market interventions that address congestions as a means of lowering pollutant emissions and a wider package of complementary measures addressing indirect demand and supply of clean vehicles might be added for success.

Air quality developments are not directly visible to residents. Without conducting and communicating an impact evaluation, public support is hard to establish. Whereas the congestion charge has gained public support after a trial implementation and a thorough communication of the results to the public, the low emission zones in Germany are still disputed because their effectiveness has not been researched scientifically nor has it been appropriately communicated to the public. The theoretical background of low emission zones is somewhat less firm. There are no actual interferences into the market, it is therefore implemented with less organisational effort and public support should be easier gained because no direct costs are involved. But the implementation of low emission zones squanders chances of improving air quality more efficiently which might be a reason for public resistance that arises despite of its theoretical ease of acceptability.

The level of acceptance and whether the beneficial effects of policy schemes (including possible health improvements, different life styles or changed transport modes) have really reached inner-city residents can be elicited by life satisfaction analysis that are combined with monitoring results of air pollution. On national levels this has already been successfully done. But since air quality directives, although determined by national laws, have to be enforced locally by policy measures, life satisfaction approaches to environmental quality have a high potential to give meaningful results on local level as well. They also pose the opportunity to give value to external costs (from the resident's point of view) and thereby create a connection to the magnitude of justifiable and acceptable road pricing schemes.

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