A cross-country comparative analysis of congestion pricing systems to achieve decarbonization goals

By

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Abstract

Alongside national and sub-national climate action, local governments play a particularly important role in implementing climate change mitigation policy. While substantial efforts are being taken to reduce GHG emissions in some communities, additional efforts are needed to encourage behavioural change in driving demand and mode of transit choice. Congestion pricing is a key policy which can motivate this change. Using a comparative analysis of global congestion pricing systems, this thesis examines government policy documents and academic literature to identify policy design features that are most desirable for achieving GHG and air quality emissions targets. Specifically, congestion pricing policies are evaluated against the criteria of implementation context, design characteristics, effectiveness, and political acceptability. In total, 16 congestion pricing systems across 11 cities in OECD member countries are assessed. Findings suggest that area-based congestion pricing systems can provide local governments with a relatively cost-effective tool to implement consistent reductions in greenhouse gas emissions in areas with a pre-existing air quality concern. Congestion pricing policies can achieve broad acceptability with thoughtful design and implementation focusing on equity and user engagement.

Keywords: congestion pricing; GHG emissions; air quality emissions; emissions abatement; cordon; zonal; facility-based

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Dedication

My sincere thanks to Dr. Rhodes for her support, patience, and guidance in making this project a success. I also owe my partner, my friends Jackie and Marissa, and classmates Luisa and Ryleigh a debt of gratitude for spending the better part of three years listening to me wax on about global congestion pricing systems. I promise I shall never speak of this research (to them) again.

Chapter 1: Introduction

The transport sector contributes to 14% of global greenhouse gas (GHG) emissions, and the sector's emissions have risen by 19% in the last decade (SLOCAT, 2021). To achieve net zero emissions by 2050, the transport sector must decarbonize rapidly (IPCC, 2021). In addition to GHG concerns, internal combustion engine vehicles are one of the main contributors to air quality emissions which negatively impact human health and lead to environmental damage (F. M. Santos et al., 2019). Air quality emissions include particulate matter (PM_{10} and $PM_{2.5}$) and nitrogen oxides (NO_x) (Ma et al., 2021; F. M. Santos et al., 2019). While substantial policy efforts have been focused on fuel switching and pollution limits, additional policy is needed to encourage behavioural change in driving demand and mode of transit choice (Lindsey & Santos, 2020; Piatkowski et al., 2019). Congestion pricing is a key policy which can motivate these changes (Lindsey & Santos, 2020). This thesis focuses primarily on GHG mitigation aspects of congesting pricing, though air quality co-benefits are also discussed.

Alongside national and sub-national climate action, local governments play a particularly important role in implementing climate change mitigation policy (Markolf et al., 2017). Major cities like Houston, Texas, emit as much as 170 million metric tonnes of GHG emissions per year (Markolf et al., 2017). Local governments have responded to the climate crisis by adopting Climate Action Plans and committing to agreements such as the U.S. Conference of Mayors' Climate Protection Agreement, the International Council for Local Government Initiatives – Local Governments for Sustainability, and the C40 network of global cities striving to reduce GHG emissions (Markolf et al., 2017). Of cities in the C40 network, 45 developed and published a climate action plan, and 21 have implemented a congestion pricing system (C40 Cities Climate Leadership Group, n.d.-b, n.d.-a; CLARS, n.d.-b).

Very little comparative analysis has been done to identify which design features are most desirable for achieving GHG emission reductions. Local governments' governance limits the instruments available to them to implement climate action, as "[r]esponsibility for transportation policy and control over transportation policy instruments are often divided across federal, state, provincial and/or municipal levels of government" (Lindsey & Santos, 2020, p. 9). In this study, the term local government refers to cities, metropolitan areas, and municipalities which manage transportation policy at a local level. Congestion pricing is enacted on locally managed streets and roads providing local governments with a unique avenue to address GHG and air quality emissions. This study provides a cross-country comparative analysis of congestion pricing systems across 11 wealthy cities within the Organisation for Economic Co-operation and Development (OECD) based on their gross domestic product (GDP). The primary research objectives are to:

1. Identify and compare the types, design features and implementation contexts (i.e., socio-economic and political conditions) for existing congestion pricing systems in the selected 11 cities, and
2. Assess the identified congestion pricing systems in terms of reported GHG and air quality emissions reductions, reported mode shift among private commuters, and reported public support as a proxy for political acceptability.

Chapter 1 introduces different types of congestion pricing systems reviewing past literature and theoretical concepts guiding the thesis. Chapter 2 provides an overview of the methods used to perform the analysis of congesting pricing systems against multiple policy attributes. Chapter 3 summarizes the results of the evaluation of four congestion pricing systems against evaluative attributes. Chapter 4 discusses the research results considering existing literature, examining the interrelationship between evaluative attributes, desirable design features for achieving emissions abatement, and equitable congestion pricing system implementation. Finally, Chapter 5 offers conclusions and policy recommendations.

1.1 Defining congestion pricing types

Congestion pricing, also known as road pricing, is a Pigouvian tax intended to restrict or reduce vehicular traffic to an area. The tax helps individual travelers internalize the negative externalities generated by their trips (de Palma & Lindsey, 2011; Lou et al., 2011). Congestion pricing is a prescriptive tax requiring all participating users to pay a fee for utilizing public roads during congested times or in specific congested areas. The structure of each pricing system acts to deter drivers from engaging in excess automobile usage (de Palma & Lindsey, 2011; Ecola & Light, 2009). Some of the systems in this study do not charge the user at the point of access, instead restricting access to the area based on vehicle emissions standards. Instead, users who do not meet the emissions standards must invest in a more efficient vehicle or use another method of transport to access the restricted area. While atypical, these systems still satisfy the criteria of a Pigouvian tax, as users must still pay – by investing in an efficient vehicle – to access the area or reduce their vehicular traffic. Historically congestion pricing has focused on reducing traffic congestion, but road transportation creates many externalities which negatively impact the public, including generating GHG and air quality emissions (Lindsey & Santos, 2020). This study focuses mainly on the negative externality of GHG emissions because transportation policy changes at the local level are a necessary part of governments' suite of climate action strategies (Lindsey & Santos, 2020).

There are three main types of congestion pricing systems: area-based, facility-based, and distance-based. However, only area- and facility-based systems have been implemented in cities to date (de Palma & Lindsey, 2011). Area-based systems charge vehicles entering and/or exiting a prescribed area using restricted checkpoints and camera enforcement to manage vehicle traffic. They have two subtypes: cordon and zonal systems. Cordon systems are generally manmade shapes (i.e., concentric circles) and only charge a toll upon entering and/or exiting the cordon (de Palma & Lindsey, 2011). Landmarks and natural features (i.e., rivers, mountains) define zonal systems, and vehicles may be charged while travelling within the defined boundary, in addition to entering or exiting (de Palma & Lindsey, 2011). Low emission zones (LEZs) are zonal systems with a primary focus on emissions reduction. LEZs have historically been excluded from area-based congestion pricing literature due to their primary focus on emissions reduction rather than traffic congestion reduction (Axsen & Wolinetz, 2021). However, congestion pricing systems are often implemented as part of a suite of governance activities in which reducing traffic congestion is only one of the objectives, which may also include reducing GHG emissions, air quality emissions, and encouraging active transit use. The substantial overlap in desired behaviour changes between traditional area-based congestion pricing systems and LEZs suggests that they can be assessed together (Axsen & Wolinetz, 2021).

Facility-based systems are most associated with road, bridge, and tunnel tolls as a form of road pricing, this system levies tolls on the facility – either on the whole road or a single lane – or on the vehicle at one or multiple points along the facility based upon distance travelled (de Palma & Lindsey, 2011). A common example is the high-occupancy toll lanes (HOT lanes) which have gained popularity in the United States. Distance-based systems are a one-to-one system where charges are determined based upon distance travelled. There is some overlap between facilities-based systems that factor distance into charges and distance-based charges (de Palma & Lindsey, 2011). Currently, there is no implementation of a solely distanced-based system to manage private vehicle congestion. The closest analog is pay-per-mile car insurance, which incentives drivers to reduce their automobile usage through lower rates tied to lower mileage.

1.2 Design characteristics of congestion pricing systems

Emerging literature is increasingly considering the role of congestion pricing systems in reducing GHG emissions at the local level (Börjesson et al., 2021; Lindsey & Santos, 2020; G. Santos et al., 2010). The literature has focused heavily on defining design features which result in successful system implementation including public acceptability, revenue use, equity, system simplicity, and privacy (Kidokoro, 2010; Selmoune et al., 2020).

1.2.1 Public acceptability

Congestion pricing often suffers from low public and political acceptability due to its prescriptiveness making it difficult for proposed congestion pricing systems to pass from the stage of a policy proposal to an implemented program (Piatkowski et al., 2019). This is because pricing systems infringe on the public's perceived "right to drive" (Lindsey & Santos, 2020, p. 3). However, increasing road capacity increases travel demand, leading to a vicious cycle resulting in overburdened urban infrastructure (Yu et al., 2017). The public more accurately has a right to accessible and affordable transportation, of which driving is one of several options.

1.2.2 Revenue use

Revenue recycling supports the concept of a right to accessible transportation by reinvesting excess revenue back into local transportation infrastructure. Reinvestment often focuses on developing modes of public transit (i.e., buses, metros) to further reduce road-based congestion (Kidokoro, 2010). Manville & King (2013) found that credible commitment – a clear agreement followed by a clear performance or action – was a key component of revenue use for achieving increased acceptability. Failure to meet implementation goals or uncertainty around how system revenue was spent negatively impacted public perception of the system (Manville & King, 2013). Gu et al. (2018) also emphasized that reducing uncertainty in revenue allocation influenced successful congestion pricing proposals. The public is familiar with the status quo and can be risk-averse when not provided with clear information (Gu et al., 2018).

1.2.3 Equity

Literature on the equity impacts of congestion pricing systems is still limited despite being a known concern for over a decade (Altshuler, 2010; Axsen & Wolinetz, 2021; Ecola & Light, 2009; Franklin, 2012; Minken & Ramjerdi, 2008; Selmoune et al., 2020; Yu et al., 2017). Consultation periods are important for identifying unintended equity impacts (Axsen &

Wolinetz, 2021). Equitable congestion pricing systems help ensure social welfare and improve policy acceptability through perceived fairness (Axsen & Wolinetz, 2021; Selmoune et al., 2020). Area-based congestion pricing systems have been shown to have a disproportionate impact on women and lower-income groups (Axsen & Wolinetz, 2021; Ecola & Light, 2009; Franklin, 2012). However, negative impacts can be mitigated through revenue recycling to public transit improvements or facility users, as well as through targeted exemptions (Axsen & Wolinetz, 2021; Ecola & Light, 2009).

Facility-based systems impact equity differently from area-based systems due to their "opt-in" design. "Do no harm" – an equity criterion frequently used in US policymaking – is a common consideration for facility-based systems such as high-occupancy toll (HOT) lanes (Altshuler, 2010). Contrary to its name, "do no harm" does not require policies to cause zero harm; instead, it encourages policymakers to consider whether a new policy would cause significant disadvantage to any group (Altshuler, 2010). While facility-based systems do not require all road users to participate, they also benefit a smaller subset of motorists (Altshuler, 2010). Of the three system types, facility-based systems are the least prescriptive.

1.2.4 Simplicity

Overly complex design can also deter the public from supporting a new system. If policymakers cannot clearly communicate the benefits and design of what will be an everyday system for commuters, it can cause a proposal to fail which has happened in Greater Manchester and Edinburgh (Selmoune et al., 2020). Making a system simpler – as Milan did by transitioning from EcoPass to Area C – can increase public acceptability and encourage further system development (Selmoune et al., 2020). Consultation and trial periods impact system complexity providing the public and industry an opportunity to become familiar with and critique a proposed system. However, Lindsey & Santos (2020) found consultation periods could be a double-edged sword, allowing politics (rather than economics) to influence decisions impacting system efficiency.

1.2.5 Privacy

Ensuring the public's right to privacy has been of significant concern when designing congestion pricing systems. A Hong Kong trial was rejected due to concerns about user privacy (Gu et al., 2018). Later, both London and Singapore addressed user privacy during their implementation process (Gu et al., 2018; Selmoune et al., 2020). Many congestion pricing systems use smart cards and transponders to facilitate pre-payment for travel into restricted zones. How much travel data these devices store can impact user acceptability of a system (Gu et al., 2018). Gu et al. (2018) place the responsibility on transport authorities to protect user privacy and ensure the security of personal information when data is shared with industry or for research.

1.3 Theoretical insights: multi-attribute policy analysis

The form and function of congestion pricing systems are impacted by a significant number of confounding factors. It is therefore unsurprising that researchers have chosen to focus their efforts on specific aspects of system implementation and effectiveness within single system types (Duncan & Graham, 2013; Gu et al., 2018; Kidokoro, 2010; Manville & King, 2013; Percoco, 2017a; Piatkowski et al., 2019; Selmoune et al., 2020). Identifying the key factors in achieving acceptable system design has received significant focus (Gu et al., 2018; Hysing & Isaksson, 2015; Percoco, 2017b; Selmoune et al., 2020), as congestion pricing systems have struggled to reach the implementation phase. Gu et al. (2018) and Selmoune et al.'s (2020) work is particularly noteworthy for identifying influencing design factors, including privacy, equity, complexity/simplicity, and uncertainty which are utilized in this study's comparative policy analysis. Cost-effectiveness, economic efficiency, and revenue use in congestion pricing systems have been studied, but the focus has been on area-based systems not facility-based systems (Axsen & Wolinetz, 2021; Börjesson et al., 2021; Fosgerau & van Dender, 2013; Kidokoro, 2010; Manville & King, 2013). The interrelationship between congestion pricing and equity has received minimal study and is generally reviewed as either an isolated characteristic or as part of the assessment of a single system (Altshuler, 2010; Axsen & Wolinetz, 2021; Ecola & Light, 2009; Franklin, 2012). Research on GHG and air quality emission reduction has been further limited, with studies focused on single systems or cities rather than any comparative analysis by type (Ma et al., 2021; Poulhès & Proulhac, 2021; F. M. Santos et al., 2019).

Multi-attribute analysis is an ideal tool for assessing a policy with many externalities (i.e., emissions, congestion, health) and linkages to other policies (i.e., public transport, parking fees, vehicle rebates) (Goulder & Parry, 2008). This type of analysis identifies multiple evaluative attributes that are important for policy implementation and ultimate success in achieving its primary goals. It uses both quantitative and qualitative metrics to assess policies against a consistent set of attributes resulting in more comprehensive policy recommendations that go beyond just the economics or politics of policy implementation.

Both climate and transportation policy studies have used multi-attribute policy analysis as a conceptual framework for analysis (Goulder & Parry, 2008; Lehe, 2019; Mahapatra et al., 2021; Rhodes & Jaccard, 2013). Lehe's (2019) literature review utilized multi-attribute analysis, assessing implementation, cost effectiveness, and mode shift but only focuses on five area-based congestion pricing systems. Unlike previous studies which largely focused on a single criterion, system or system type, this thesis utilizes a multi-attribute policy analysis to assess a broad selection of evaluative attributes across multiple system types worldwide to ultimately identify the best design characteristics for GHG emissions abatement.

This thesis contributes to the literature by distinguishing congestion pricing as an important class of GHG emissions reduction policy, reviewing its use in a cross-country context, and drawing key lessons for future global policies design and implementation. Including all types of congestion pricing systems - rather than a single type - provides a novel perspective on the impact of design features on GHG emissions reduction at the local community level.

The study examines the application of congestion pricing systems in terms of their implementation context, design characteristics, effectiveness, and political acceptability. Each system is evaluated across a range of common attributes (see Table 1) used in environmental policy and transportation analysis (Gu et al., 2018; Rhodes et al., 2021; Selmoune et al., 2020). These attributes are drawn from studies focused on policy and design features for achieving successful implementation. While this study only focuses on successfully implemented congestion pricing systems, research into failed systems (e.g., Edinburgh, New York) is also important for identifying barriers to future implementation. Policy implementation is measured by the presence of public engagement and trust building activities during the proposal phase, activities include trial periods, public referendums or bylaw implementation, professional studies, and public consultation and surveys (Gu et al., 2018; Hysing & Isaksson, 2015; Selmoune et al., 2020). Professional studies are defined as impact studies requested by government to assess the effectiveness of proposed systems (i.e., road studies, emission abatement studies) and are performed by academics or private companies. Public consultation and surveys include townhalls, focused media outreach, and pre-implementation stated preference surveys performed by or on behalf of government[1].

Table 1: Evaluative attributes for examining congestion pricing systems (Gu et al., 2018; Rhodes et al., 2021; Selmoune et al., 2020)

Attribute	**Definition**
Implementation context	
Policy implementation process	Description of the original policy and process for the design and implementation including trial and/or referendum periods, engagement with the public and professional studies
Design characteristics	
Type of congestion pricing system	Categorizes the system as one of the defined types of congestion pricing system
Privacy	Ability to limit collection of user data and maintain user anonymity
Simplicity	The convenience, understandability, and usefulness of a pricing system's design for road users and the public
Revenue use	How system revenue in excess of operating costs was utilized
Effectiveness	
Emissions abatement	The magnitude of GHG and air quality emissions avoided because of the pricing system
Modal shift	The magnitude of drivers transitioning from single occupancy internal combustion engine vehicles to alternative modes of transit
Net revenue	Annual net revenue of the pricing system

[1] In the United States, stated preference surveys are generally performed at the federal level – rather than local – by the U.S. Department of Transportation which provides oversight and funding to major highway infrastructure projects (U.S. Dept of Transport, 2020).

Attribute	Definition
	Annual net revenue in CAD$2020, with original currencies also being listed
Equity impacts	Impact of the pricing system on low-income earners and marginalized group's ability to access the facility or restricted area
Political acceptability	
Public support	Reported public support for a policy pre- and post-implementation. Acts as a proxy for political acceptability

Congestion pricing system enforcement method is used to measure the impact on user privacy. The more data collected on the user in the process of enforcing the system (i.e., travel data, banking data) the greater the impact on the user. System simplicity focuses primarily on pricing method and secondarily physical design. Pricing can be fixed, variable or dynamic and influenced by factors including but not limited to vehicle emission type, facility congestion level, and time of day. The more complex the combination of pricing factors, the less simple the system. Additionally, physical design features can make a system more complex for the user to interact with (i.e., reversible lanes, unlabeled boundaries) and are therefore considered as part of system simplicity.

Revenue use is measured by whether revenue recycling occurs, and the type of revenue investments made (i.e., infrastructure versus operations, vehicle versus public transit). Net revenue is an approximate annual value based upon available operational expense and gross revenue data. It is presented throughout the study in the original currency and in a standard conversion to 2020 Canadian dollars (CAD$2020) using a currency and inflation conversion calculator from the US Official Inflation Database (Alioth Finance, 2023, May 10). Neutral to high net revenue is acceptable; however, in systems with revenue recycling policies higher net revenue is a positive as these funds serve to improve either the congestion pricing system or related transportation activities (Kidokoro, 2010; Manville & King, 2013).

Emissions abatement is assessed as either an annual average reduction in emissions concentrations or a total percent reduction in emissions concentrations based on jurisdictional reporting. GHG emissions included carbon dioxide (CO_2) and ozone (O_3). Key air quality emissions include particulate matters, PM_{10} and $PM_{2.5}$. NOx, which encompasses emissions such as nitrogen oxide (NO) and nitrogen dioxide (NO_2), is primarily an air quality emission but is also an indirect GHG emission.. Mode shift is assessed as either a change in traffic composition or a change in bus ridership based on jurisdictional reporting. Modal shift is secondarily tied to GHG emission abatement as users transition to more environmentally conscious transit options.

Equity impacts measure the pricing system's impact on low-income earners and marginalized groups in their ability to access the facility or restricted area. A well-built system should have features which allow marginalized groups to interact fairly with the congestion pricing system. Public support is measured using mostly quantitative pre- and post-implementation user preference data assessing how positive the public's perception of the system and its impacts is.

Public support data come from a combination of government and news sources and is a proxy for political acceptability. Where quantitative data are not available, qualitative data are used.

Chapter 2: Methodology and Methods

2.1 Content analysis

Content analysis is employed to perform a multi-attribute trade-off analysis of congestion pricing systems. Content analysis identifies themes and patterns within data through the systematic interpretation of the text and qualitative materials (Cho & Lee, 2014). This method is often used in research "to answer questions such as what, why and how, and… [identify] common patterns in the data… to organize text with similar content" (Cho & Lee, 2014, p. 6). Policy and news documents can be incorporated into the flexible structure of content analysis to identify commonalities across large amounts of data (Bista et al., 2021).

Transportation policies and government documents have been widely studied via content analysis (Bista et al., 2021; Leung et al., 2019; Vonk Noordegraaf et al., 2014). Pairing content analysis and multi-attribute analysis reinforces the best attributes of both tools--content analysis supports new insights and exploration of identified phenomena (the evaluative attributes in Table 1) while multi-attribute analysis provides a way to frame new insights across multiple criteria which are difficult to measure using a single economic analysis tool (Bista et al., 2021; Goulder & Parry, 2008).

This thesis uses content analysis to assess the main design features and implementation contexts of congestion pricing systems in economically similar cities within OECD member countries. For inclusion in the project, a pricing system met the following criteria:

- implemented on or after January 1, 2000 (pricing systems in the planning phase or temporary pilot projects were excluded from this study);
- implemented in a city within an OECD member country;
- implemented in a city with a gross domestic product (GDP) of US$100 billion or higher in 2020[2];
- applied to private vehicles and be of sufficient scale[3]; and
- met one of the congestion pricing system definitions provided above.

Content analysis employed both qualitative and quantitative methods during data analysis. Qualitative analysis included written descriptions of design features and implementation contexts of congestion pricing systems. Quantitative analysis included comparing reported user privacy, observed GHG and air quality emissions reductions, and reported public support levels for regulations based on published literature. The study used peer-reviewed academic literature, public reports, government legislation and communication materials, and media releases.

This method has limitations. First, local governments' transportation data requirements are not focused on the issues of emissions reduction and are not standardized across jurisdictions –

[2] Utilizing a GDP floor limits the project to systems in large, metropolitan areas to ensure comparability across economies of scale.
[3] Hamburg, Germany's low-emission zone was excluded due to the policy only applying to two streets within the city.

making comparing findings across jurisdictions difficult. Therefore, some data was excluded when its format was incompatible with most other jurisdictions. Second, the studied congestion pricing systems have not been static in their design over time but the thesis reports on each policy's performance at a single point in time potentially limiting a full representation of the system's implementation context. Third, content analysis could have suffered from recall bias (i.e., where the researcher misinterprets a communication's intention) which is of greater concern for policies in non-English speaking countries where translations were used to collect data from government websites (Maier, 2017). Fourth, there is a difference in scale between area-based and facility-based systems which may limit the comparisons which can be made between them. Despite these limitations, the study takes steps to address data comparability (e.g., standardizing average net revenue in CAD$2020), identify outliers where present, and collect data from a range of sources to help reduce recall bias.

2.2 Data collection and analysis

Data collection occurred in four steps. First, a short list of cities was identified that met both OECD member status and the GDP threshold inclusion criteria. Second, relevant congestion pricing systems were identified using the Urban Access Regulations in Europe (UARE) database, the United National Framework Convention on Climate Change (UNFCCC) Biennial Reports Data Interface, and a review of the associated literature as not all OECD countries consider emissions reduction the primary goal of their congestion pricing systems.

The UARE provides information by city on urban access-related regulation schemes, road tolling, low emissions zones, and other access restrictions. The local government's name was entered into the UARE's search bar and, if available, selected – displaying all recent municipal access restriction policies. Database queries for the UNFCCC included mitigation policies for all OECD countries classified as "economic," "fiscal," "regulatory," "other," or "not specified" within the transportation sector for all greenhouse gases. The query only included adopted and implemented policies.

Third, keyword searches of the literature databases – Google Scholar and Scopus – were conducted for each pricing system and its associated country using the city's name and the pricing system type. For example, "Stockholm" AND "congestion price" OR "road price" or "Milan" AND "low emission zone" OR "LEZ". Finally, design characteristics were reviewed against the attributes in Table 1 based on descriptions within national reports, scholarly literature, and targeted reviews of government documents (i.e., regulations, policy briefs, and communication materials). In cases where data on a particular attribute were unavailable, the study does not report on that attribute.

The study identified 16 congestion pricing systems across 11 cities which met the inclusion criteria. Figure 1 provides an overview of how the studied congestion pricing systems are distributed at the local and national level by excluding repeated locations.

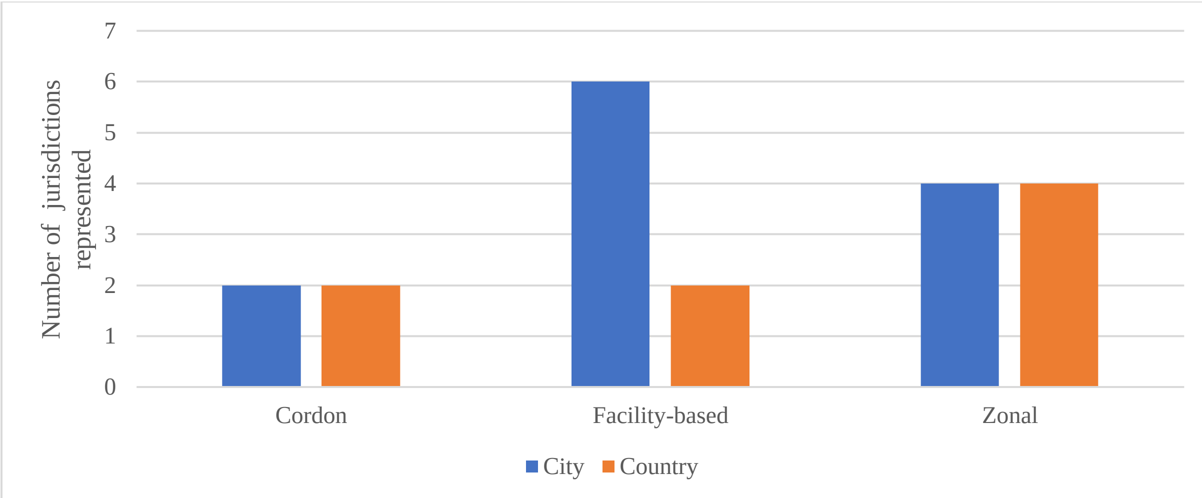

Figure 1: The figure displays how different congestion pricing system are distributed across jurisdictions at the local and national levels excluding repeated locations. For example, three facility-based systems within the United States only count as one unique jurisdiction represented at the national level.

While facility-based systems were the most common, consisting of half of all systems, they were located almost exclusively in the United States. Zonal systems showed the most jurisdictional diversity with European cities favouring area-based pricing systems. Several systems initially identified during the review of the literature and the UNFCCC database (i.e., a total of 1,314 national and sub-national climate mitigation transportation-related policies were found of which 10 met the inclusion criteria) were only short-term pilot projects or lacked sufficient available data for inclusion (i.e., Vienna's low emission zone; Portland's HOT lanes). Design feature assessment was performed separately in cases where cities have implemented multiple congestion pricing systems. As a result, some cities are included more than once within the study (see Table 2).

Table 2: List of implemented congestion pricing systems by type, city, and country (CLARS, n.d.-d; Gu et al., 2018; Organisation for Economic Co-operation and Development, n.d.; Selmoune et al., 2020)

System type		**City implemented**
Area-based	Cordon	• Milan, Italy (EcoPass) • Milan, Italy (Area C) • Stockholm, Sweden
	Zonal	• Paris, France • Milan, Italy (Area B) • Lisbon, Portugal • London, UK (congestion charge) • London, UK (low-emission zones)

System type	City implemented
Facility-based	• Melbourne, Australia • Atlanta, USA • Denver, USA • Houston, USA • Miami, USA • Minneapolis, USA (I-394) • Minneapolis, USA (I-35W)

Chapter 3: Results

3.1 Cordon systems

This section reviews three cordon systems across Milan (EcoPass and Area C) and Stockholm. Appendix A: Evaluative criteria of cordon pricing systems summarizes the evaluation against the multi-attribute policy framework from Table 1.

3.1.1 Milan – EcoPass

EcoPass was implemented on January 2, 2008, the first congesting pricing system of its kind in Italy (Beria, 2016). Intended to help address Milan's air pollution concerns, the city had repeatedly violated European Commission targets for particular particulate matter (PM_{10} and lower fractions) emissions (Beria, 2016; Lehe, 2019). The city risked fines if the problem remained unaddressed (Beria, 2016; Lehe, 2019). While a formal study of road pricing options was performed in 2001, most debate and policy planning for the EcoPass measure did not occur until 2006 due to changes in mayoral leadership (Lehe, 2019). A public consultation was held in 2011 to determine if the system would be continued (see Milan – Area C), and EcoPass received a 79% voter approval rating (Percoco, 2013).

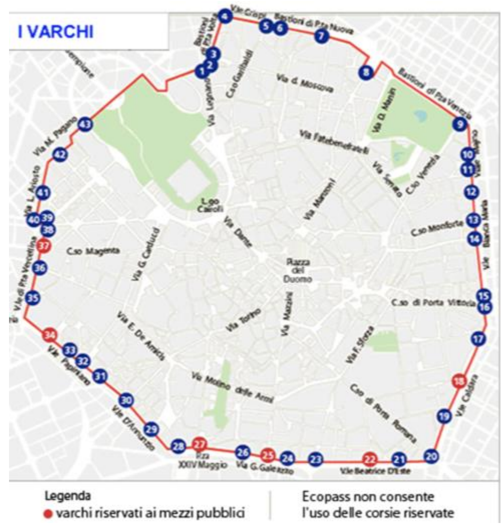

Figure 2: EcoPass charging cordon, Milan. The solid red line indicates the codon perimeter while the circles indicate access points for users.

The system (see Figure 2) covered an $8km^2$ surrounding the city center – corresponding to 16^{th}-century city walls (Beria, 2016; Lehe, 2019; Percoco, 2013). Fourth-three access points operated from 7:30 AM to 7:30 PM on weekdays and scanned license plates of vehicles entering the cordon utilizing Milan's pre-existing camera infrastructure (Lehe, 2019). This enforcement method offers no opt-out option, and users are tracked at access points – though not within the system itself – resulting in significant loss of user privacy. The system is simple for users to understand with vehicles charged a flat rate based on their engine emission standards, motorbikes, alternative fuel vehicles, and EURO 3 and EURO 4 compliant vehicles were exempt from charges (see Appendix B: EURO vehicle emissions compliance standards) (Lehe, 2019; Percoco, 2013). Exemptions improve user equity and system acceptability by reducing the financial burden for users who have taken significant action to reduce their emissions (i.e., transitioned to an alternative fuel vehicle).

While detailed GHG and air quality emissions data was not collected prior to implementation, post-implementation studies found that the cordon had an early positive impact on emissions reduction (Beria, 2016; Percoco, 2021). As the cordon encouraged mode shift to more efficient vehicles among users, the rate of emissions abatement steadily declined (Beria, 2016). Estimates are based on the difference between the vehicles entering the cordon before and after implementation (Rotaris et al., 2010). Information on revenue use is limited; however, costs have been described as low due to the system's use of pre-existing camera infrastructure (Lehe, 2019). Set-up costs were approximately €6.5M in 2008 (CAD$11.1M[4]), while the annual revenue was €11.2M (CAD$19.1M) for the same year (Croci, 2016; Lehe, 2019). The system's revenue was recycled into public and active transit infrastructure, including buses, trams and bike shares (Lehe, 2019). Research into the equity impacts of the EcoPass system is also limited. Percoco (2014) estimated the charge's effect on housing prices within the cordon area, Milan, and the province. After implementation, there was an overall negative impact on housing prices (Percoco, 2014). The tested area lost significant value, between €60.6 and €180.3 per square metre (sq. m.) (CAD$97.19 to CAD$289.18 per sq. m.), within one year of Ecopass' implementation (Percoco, 2014). While many factors could impact this change in value, the potential negative impact on residents within the cordon zone should be further investigated.

3.1.2 Milan – Area C

The Area C charging zone was implemented on January 16, 2012, with the intention of expanding and reframing the Ecopass system to address flaws and build on its public popularity (Hensher & Li, 2013). Area C maintained the same charging zone and number of entry points as its predecessor but changed the fee schedule (Hensher & Li, 2013). As Area C uses the same enforcement method as Ecopass, it presents the same privacy concerns for users. While Ecopass uses a variable charging rate, Area C uses a fixed rate system. All vehicles entering the cordon between 7:30 am and 7:30 pm during weekdays are charged a flat fee at either the general, resident, or commercial vehicle rate – reducing the number of fee types and making the system even simpler than its predecessor (Hensher & Li, 2013; Lehe, 2019). There are exemptions for alternative fuel vehicles, public and emergency vehicles, and motorcycles; EURO 0 petrol vehicles and EURO 1, 2 and 3 diesel vehicles are banned from entering entirely (Hensher & Li, 2013; Lehe, 2019). The additional exemptions and restrictions increase perceived fairness, which is necessary for achieving public acceptability.

Unlike its predecessor, Ecopass, there is a sharp and continuous emissions reduction with Area C – also influenced by overall traffic reduction and fleet renewal in Milan (Beria, 2016). Milan increased its transparency regarding costs, revenues and reinvestment, and emissions reporting with the implementation of Area C. The system's annual operating costs approximately €14M (CAD$22.8M), but gross revenue returns regularly double to triple cost of operation (Croci, 2016; Lehe, 2019). The first year of implementation recycled a total €20M (CAD$31.8M) back into public and active transport (Agenzia Mobilità Ambiente e Territorio, 2022). Ten million (CAD$15.9M) in upgrades to buses, trams, and subways significantly increased the number of trips per day and extended peak time service (Agenzia Mobilità Ambiente e Territorio, 2022). The remaining €10M (CAD$15.9M) increased cycling access by 75%, redeveloping infrastructure to make it more sustainable and supportive for active and public transit users (Agenzia Mobilità Ambiente e Territorio, 2022). Area C's significant revenue recycling supports a positive relationship between the public and government, developing a credible commitment to policy change which can increase public acceptability of congestion pricing systems. Revenue recycling into public and active transit also helps reduce the equity impacts of a congestion

[4] Converted to 2020 CAD$ for the purpose of comparing across congestion pricing systems.

pricing system by making alternative transport options more accessible for users priced out of the system.

3.1.3 Stockholm

The Stockholm Congestion Tax (SCT) was implemented permanently on August 1, 2007, with the aim of reducing vehicle congestion and improving the environment (Coria et al., 2015; Lehe, 2019). Stockholm had spent the better part of two decades exploring the viability of a congestion tax, with the matter coming to a head in 2000 as the city implemented a commission on infrastructure (Lehe, 2019). Prior to implementing a permanent program, Stockholm performed a seven-month trial period (January to July 2006) – which included some public transit expansion – followed by a public referendum vote (Lehe, 2019). Prior to the trial period, public support for the system was low (36%); however, support sharply increased as the trial resulted in tangible congestion reductions with 53% of voters ultimately supporting the decision to retain the system permanently (Lehe, 2019).

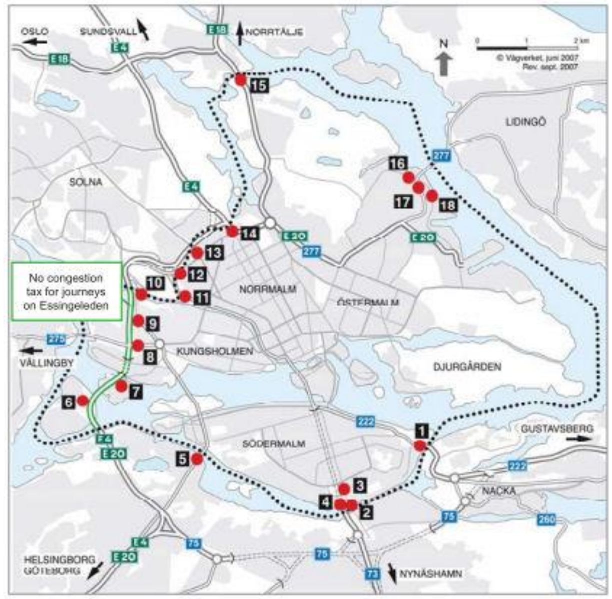

Figure 3: SCT charging cordon as of January 2, 2020. Dotted line indicated the cordon boundary, while the red dots indicate access points for users (CLARS, n.d.-a)

The system (see Figure 3) covers 35km^2 including Stockholm city center and part of the Essingeleden (an expressway) (CLARS, n.d.-a; Coria et al., 2015; Lehe, 2019). Vehicles are charged upon entry and exit into the cordon at one of 18 control points (CLARS, n.d.-a; Lehe, 2019). Drivers are not required to stop and pay at control points, instead a photo is taken of their license plate (Lehe, 2019). This enforcement method offers no opt-out option and users are tracked at access points – though not within the system itself – resulting in some loss of user privacy. The cordon is only active during the day from Monday to Friday[5] and uses a time-variable tax to charge users based on the time they enter and/or exit the cordon; the charge changes at 30-minute intervals and has both on- and off-season pricing (Lehe, 2019; Swedish Transport Agency, 2021b). Fees can be paid via direct debit, electronic invoice, or a monthly payment slip (Swedish Transport Agency, 2021a). The high variability in pricing – users must factor in weekday, time, and season – results in a more complex congestion pricing system despite the entry and exit system being relatively simple.

[5] Inactive holidays, the month of July except the first 5 weekdays, Red Day, and the day before Red Day except the day before Good Friday, day before Ascension Day and day before All Saints' Day as well as the day before May Day and the day before National Day if they fall on a weekday other than Saturday.

Changes to emission rates within the cordon have not been tracked; however, CO_2 emissions from new passenger cars and light trucks across the whole of Sweden have been tracked (Swedish Transport Agency, 2022). Some of the fleet renewal may be attributed to congestion pricing systems. For all new Swedish vehicles, there was a 4% reduction in g/km of CO_2 emitted between 2006 and 2007, and a 12% reduction between 2006 and 2009 (Swedish Transport Agency, 2022). The SCT regularly earns four to five times more annual revenue than is needed to fund its annual costs which is beneficial as it has a revenue recycling scheme (Lehe, 2019). Revenue has been recycled into both public transit projects and new road infrastructure (Hysing & Isaksson, 2015). The system and transit investments have led 74% of drivers to either shift to public transport, change their route, reduce trip frequencies, or even cancel travel (Selmoune et al., 2020). This represents reduced equity impacts of the congestion pricing system through improved access to alternative transit. Two official travel surveys were completed as part of the SCT trial's evaluation to identify any equity impacts (Franklin, 2012). The studies did not find regular changes in trip-making across income groups. The most significant finding was that "men, who tended to travel more by car than women, reduced their trips to a larger extent than women" (Franklin, 2012, p. 31). Franklin (2012) used the official travel survey data to further evaluate the equity impacts of the system and found that long-term mode shift between private vehicles and public transit was significantly impacted by two variables: access to a car and possession of a transit pass.

3.2 Facility-based systems

This section reviews seven facility-based systems located across Melbourne, Atlanta, Denver, Houston, Miami, and Minneapolis (I-394 and I-35W). Appendix C: Evaluative criteria of facility-based pricing systems summarizes the evaluation against the multi-attribute policy framework from Table 1.

3.2.1 Melbourne

The Eastlink tollway network was established in 2008 (Li & Hensher, 2010). The tollway design focused on reducing north-south traffic congestion resulting from Melbourne's expanding population and environmental sensitivity (State Government of Victoria et al., n.d.). It is developed and managed through a public-private partnership (PPP) between the Government and ConnectEast. The public was initially hostile towards the project due to the long implementation time and the perceived disturbance to community structure (State Government of Victoria et al., n.d.). The project addressed public concerns through a comprehensive information campaign focused on engaging with the community, informing them of ongoing activities, and listening to concerns (State Government of Victoria et al., n.d.). A year after opening, the newspaper Manningham Leader's My Melbourne survey found that 67% of Melbourne respondents were willing to pay tolls to fund major projects; a distinct change from the initial negative public opinion of the EastLink project (Road Tolls in a Turnaround, 2007).

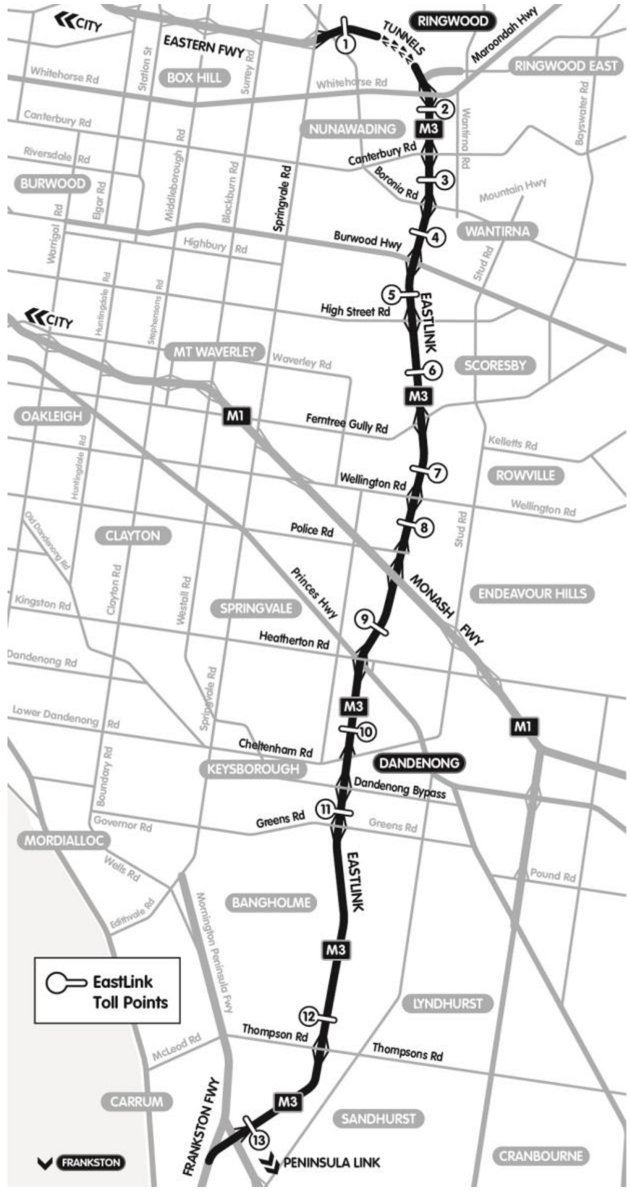

Figure 4: EastLink toll network. Bold line indicates the tolled road; the circled numbers indicate tolling points (EastLink, n.d.-a).

The state of Victoria's largest toll road, EastLink comprises 39km of tolled roads connecting the Eastern, Monash, Frankston, and Peninsula Link freeways (see Figure 4) (EastLink, n.d.-a). Tolls are a variable rate based on distance travelled along the tolled facility and vehicle class – a maximum daily toll cap is set based on trip type. Vehicle classes include cars, light commercial vehicles, heavy commercial vehicles, motorcycles, and taxis (EastLink, n.d.-c). Trip type also modifies car tolls – EastLink defines these as a normal trip, trip taken on a weekend or public holiday, or single toll zone trip (EastLink, n.d.-c). All vehicles except taxis can purchase trip passes, which allow the user to pay a flat rate for a single trip in one direction (EastLink, n.d.-b). Users can pay for tolls through a pre-paid tag account, a pre-paid non-tag account, a non-account trip pass, invoicing by trip (individuals), or through monthly invoicing (businesses only) (EastLink, n.d.-b). Advertised as the most affordable way to pay tolls, tag accounts charge the fewest processing fees; however, to utilize either of the EastLink account options, an opening payment is required for activation (EastLink, n.d.-b).

EastLink monitors and publishes aggregated daily air quality data from its tunnels. A brief increase in air quality emissions occurred upon initial implementation, but EastLink has since seen a 6% decrease in overall air qulaity emissions (EastLink, n.d.-d). In EastLink's 2021 Sustainability Report, emissions were well below EPA license limits in all categories. Unfortunately, EastLink has not been transparent on the annual operating costs of the system, though advertised implementation costs were AU$2.5 billion (CAD$2.98 billion) (State Government of Victoria et al., n.d.).

In 2019, EastLink implemented a Hardship Policy to support individuals experiencing financial hardship (EastLink, 2019). While the Hardship Policy (2019) only addresses sudden and temporary changes to finances, it supports user equity by reducing short-term barriers to access through hardship assistance such as payment extensions, payment plans, the reduction or waiver of debt, or temporary deferral of payment. In FY2021, EastLink issued 3,231 hardship payment plans – down 17% from the previous year; however, the average dollar value per plan increased to AU$292 (CAD$267) – 16% higher than FY2020 (Spencer-Roy et al., 2021).

3.2.2 Atlanta

On October 1, 2011, the State of Georgia completed its conversion of existing high-occupancy vehicle lanes on the I-85 expressway to high-occupancy toll lanes (HOT lanes) (Sheikh et al., 2015). The transition was made to a tolled system to address high congestion rates in high-occupancy lanes during peak travel hours and meet the federally mandated 40 mph minimum highway speed (Muchuruza & Mussa, 2011; Sheikh et al., 2015). Stated preference surveys taken both pre- and post-implementation are commonly used to assess HOT lanes acceptability and impact (Guensler et al., 2020; Pessaro & Sangchitruksa, 2014; Sheikh et al., 2015). Pre-implementation public opinion gathered on the I-85 Express Lane project found only 9% of respondents in favour and 68% opposed (Hart, 2012). However, Guensler et al. (2020) found that, ultimately, HOT lane implementation led to a more positive public perception of commute conditions.

The I-85 Express Lanes extend 15 miles from Chamblee Tucker Road (just south of I-285) to Old Peachtree Road in Gwinnett County (SRTA, n.d.-a). The optional HOT lanes run alongside the non-tolled lanes, allowing users to merge into and out of tolled lanes at will (SRTA, n.d.-d). The system uses dynamic pricing practices, adjusting toll prices in real-time to meet changing travel demand (SRTA, n.d.-b, n.d.-d). The minimum per-mile rate is US$0.10 (CAD$0.14); during particularly low demand periods, a flat US$0.50 (CAD$0.69) per trip charge replaces the per-mile toll. Motorcycles, alternative fuel vehicles (not including hybrid vehicles), emergency vehicles, and vehicles with 3 or more occupants (high-occupancy vehicle (HOV3+)) are exempt from tolls on the I-85; vehicles with 2 or more axles and/or 6 or more wheels are not eligible to use the express lanes (SRTA, n.d.-a, n.d.-c). The additional exemptions and restrictions increase perceived fairness, which is necessary for achieving public acceptability. All express lane users must have a Peach Pass or "Banc Pass Pay n Go" to use the tolled lanes, including exempt vehicles[6] (SRTA, n.d.-c). Automatic vehicle identifier scanners are hung on gantries over express and general-purpose lanes to identify Peach Pass and Banc Pass users (Sheikh et al., 2014). Thirty-five gantries service the express lanes, and another 13 service the general-purpose lanes (Sheikh et al., 2014). Enforcement cameras run alongside the lanes to capture the license plate data of users without a pass (Sheikh et al., 2014). Both the Peach Pass transponders and the license plate capture system reduce user privacy, capturing vehicle travel data at every gantry passed rather than just a single entry or exit point.

Xu et al.'s (2017) analysis of emissions abatement and modal shift after Atlanta implemented HOT lanes on the I-85 found a change in on-road vehicle composition, including increased bus ridership. Between 2011 and 2012, managed HOT lane distribution of passenger vehicles and express buses increased by 16 and 18% respectively (Guensler et al., 2020; Xu et al., 2017). Atlanta invested in expanded express bus service as part of the HOT lane transition (Xu et al., 2017). The Atlanta Regional Commission's public opinion survey found that 41% of the public favoured public transit improvement to address traffic, while 30% favoured better roads and highways (Simmons, 2014).

After its first year of implementation, the I-85 saw some minor reductions in GHG and air quality emissions (Xu et al., 2017). Khoeini and Guensler's (2014) socioeconomic assessment of the I-85 analyzed household usage of general purpose, HOV and HOT lanes the year before and the year after HOT lane implementation. The HOT market[7] and HOV-HOT market[8] were almost 50% more likely to include high-income users than very-low- and low-income users (Khoeini & Guensler, 2014). Further survey data also found that Atlanta's HOT lanes led to the dissolution of pre-existing carpool groups and reduced the likelihood of commuters to carpool (Guensler et al., 2020).

3.2.3 Denver

Planning for Denver's 1-25 Central Express Lanes began in 1999 to increase the utilization of pre-existing HOV lanes without degrading service for users (Goel & Burris, 2012; U.S. Dept of Transportation, 2010a). The HOV-to-HOT conversion was finally implemented in June 2006, almost a decade later. Capital costs to implement the project were approximately USD$10M (CAD$18.5M) (U.S. Dept of Transportation, 2010a). The I-25 Central Express Lanes consist of two reversible lanes extending 9 miles (Colorado Dept of Transportation (CDOT), n.d.; U.S. Dept of Transportation, 2010a). The lanes connect North I-25/US 36 to 120th Avenue Express Lanes and the U.S. 36 Express Lanes and are separated from the general-purpose lanes by a concrete barrier (Colorado Dept of Transportation (CDOT), n.d.; Goel & Burris, 2012). Lane operations cost approximately USD$2.4M (CAD$4.4M) annually (U.S. Dept of Transportation, 2010a).

Denver's I-25 Central Express Lanes utilize a variable, time-of-day pricing system – the time the user enters the facility determines the toll cost. During the week, tolls operate on the southbound

[6] Emergency vehicles are not required to have a pass.
[7] New high-occupancy lanes users who used HOV lanes 20% or less prior to HOT lane implementation.
[8] Used HOV lanes 20% or more prior to implementation and used HOT lanes 20% or more post-implementation.

lanes from 5 am to 11 am and on the northbound lanes from noon to 3 am to abate traffic to and from downtown Denver. On weekends, the northbound lanes open at noon Friday and remain open until 3 am on Monday (Colorado Dept of Transportation (CDOT), n.d.). Express lane users can pay tolls using a transponder connected to a pre-paid ExpressToll account or the License Plate Toll (LPT) program, which photographs the front and rear license plates and mails a statement to the vehicle owner's address on file with the Department of Motor Vehicles (ExpressToll, n.d.). Drivers who use a pre-paid toll account receive significantly discounted toll rates – up to 65% savings – and enrollment in a rewards program compared to individuals who rely on the LPT program (CDOT, n.d.; ExpressToll, n.d.). HOV3+ and motorcyclists are exempt from tolling; however, HOV/carpool drivers are required to have a pre-paid transponder to verify to verify passenger count (Colorado Dept of Transportation (CDOT), n.d.). The additional HOV3+ and motorcyclist exemptions increase perceived fairness, which is necessary for achieving public acceptability.

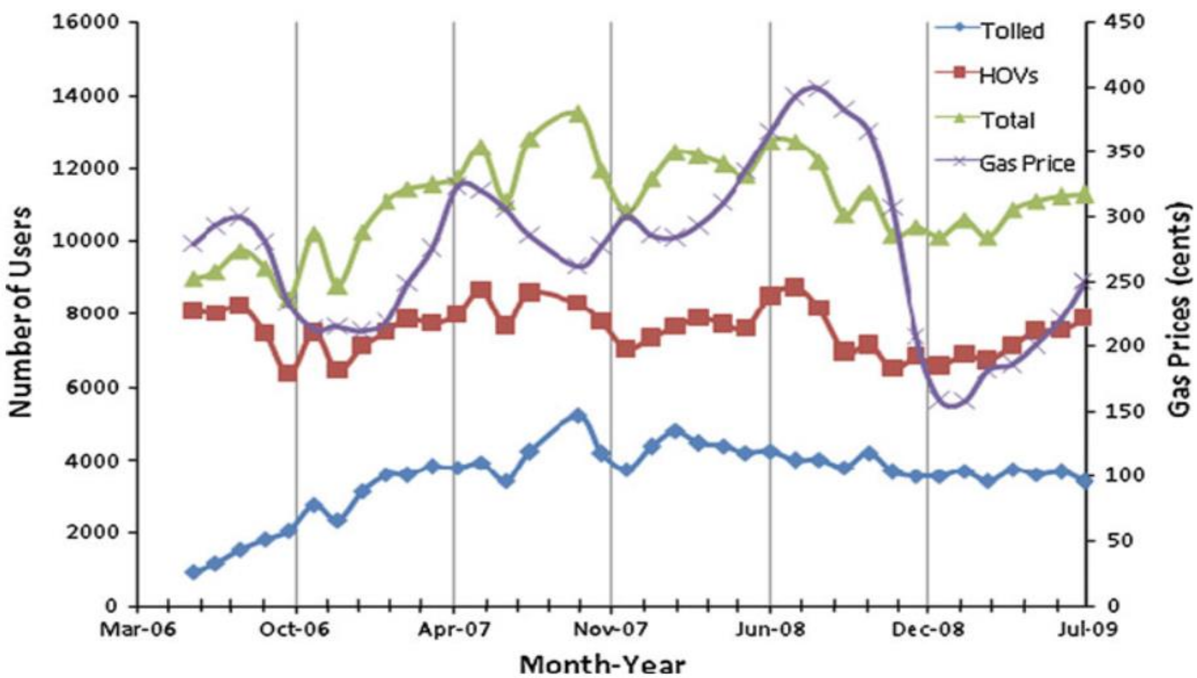

Figure 5: Change in I-25 express lane usage in relationship to gas prices (Goel & Burris, 2012).

The I-25 Express Lanes have an annual revenue of approximately USD$5.4M (CAD$9.9M), including fines and fees (U.S. Dept of Transportation, 2010a). Information on revenue usage is not available. Goel & Burris (2012) found that the express lanes implementation had a limited impact on user mode shift to bus and carpooling. Of the survey's respondents, 54% drove alone four or more days a week, irrespective of express lane usage (Goel & Burris, 2012). Single-occupancy ridership is high despite equity measures such as the implementation of park-and-ride lots to encourage carpooling – there are three lots near the I-25 (Goel & Burris, 2012). In the lanes' first four years of implementation, gas prices also significantly impacted users' mode of transit selection (see Figure 5) (Goel & Burris, 2012).

3.2.4 Houston

Houston, Texas introduced the QuickRide program to the U.S. 290 in November 2000 (U.S. Dept of Transportation, 2010d). QuickRide replaced an underutilized HOV3+ lane with a HOT lane (express lane) (U.S. Dept of Transportation, 2010d). Figure 6 depicts the express lane, spanning 13.5 miles and separated from regular traffic by a concrete barrier (U.S. Dept of Transportation, 2010d). The single express lane is reversible, running towards downtown Houston in the mornings and away in the afternoons (METRO, n.d.). The U.S. Department of Transportation (2010) reported that the capital costs to transition from HOV to HOT lanes were approximately USD$0.05M (CAD$0.1M).

Figure 6: Reversible HOT lane on the U.S. 290, Houston, TX

Houston's express lane utilizes variable, time-of-day pricing – the time users enter the facility determines the flat cost of their trip (see Figure 7). The express lane operates Monday through Sunday, opening for inbound traffic from 5 am to 11 am and outbound traffic from 1 pm to 8 pm (METRO, n.d.). Express lane users are restricted to HOV3+ and HOV2+ users from 6:30 am to 8 am and 4:30 pm to 6 pm, respectively (METRO, n.d.). HOV users are not tolled during the restricted period (METRO, n.d.). METRO buses, vanpools, emergency vehicles, and motorcycles are exempt from tolls, and qualified U.S. military veterans can receive discounted tolls (METRO, n.d.; U.S. Dept of Transportation, 2010d). Toll exemptions for HOV users and discounts for veterans increase perceived fairness which is necessary for achieving public acceptability.

Figure 7: Toll gantry over the U.S. 290, Houston, TX

All users must pay for tolls using an approved toll tag through Harris County EZ TAG, TxTAG, NTTA (North Texas Tollway Authority), Kansas Transit Authority (KTA), Oklahoma Turnpike Authority (OTA), Dallas North Tollway (DNT), or Bancpass (METRO, n.d.). METRO, Houston's public transportation service provider, manages toll system information. Despite having transparent financial and ridership data for bus, park and ride, and metro services, METRO does not supply this data for Houston's express lanes. As users are only charged upon entry into the facility, the travel data collected by the toll tag should be limited. Both METRO bus and park-and-ride services are integrated with the express lane providing more equitable access options to the express lane (U.S. Dept of Transportation, 2010d). As of 2010, the annual operating cost of the express lane was approximately USD$0.14M (CAD$0.3M) with an approximate USD$0.15M (CAD$0.33M) annual revenue (U.S. Dept of Transportation, 2010d).

3.2.5 Miami

The conversion of HOV lanes to HOT lanes on Miami, Florida's I-95 (95 Expressway) began in February 2008 with the aim of reducing traffic congestion, increasing highway capacity, encouraging public transit use and carpooling, and improving trip predictability for users (FDOT, n.d.-c; U.S. Dept of Transportation, n.d.-b, n.d.-a). Conversion occurred in three phases. Phase 1A focused on the 7 miles of northbound lanes, including "re-striping the northbound lanes to create two express lanes and four regular travel lanes and installing electronic signage and tolling equipment" (U.S. Dept of Transportation, n.d.-b). Electronic tolling opened in December 2008, completing Phase 1A. Construction for Phase 1B began summer of 2008 with identical work on the southbound lanes; tolling started in January 2010 (U.S. Dept of Transportation, n.d.-b). A U.S. Department of Transportation survey conducted during Phase 1 found positive public support for the HOT conversion project, with 76% of respondents saying the service was faster and more reliable service and 56% in favour of expanding the project (U.S. Dept of Transportation, n.d.-a).

Figure 8: Map of Phase 3 implementation plan for Miami's I-95 Expressway (FDOT, n.d.-c)

Phase 2 began in November 2011 and expanded the express lanes 14 miles in both directions by converting pre-existing HOV lanes (U.S. Dept of Transportation, n.d.-b). The expansion also included ITS component installation, interchange modification, bridge widening, and noise wall installation (U.S. Dept of Transportation, n.d.-b). Tolling on the 95 Expressway extension began in October 2016 (U.S. Dept of Transportation, n.d.-b). Figure 8 depicts Phase 3, a further extension of the HOT lanes beginning mid-2016 (FDOT, n.d.-c; U.S. Dept of Transportation, n.d.-b). Like Phase 1, this extension was sub-phased with the intention of extending the express lanes an additional 29 miles by 2024 (FDOT, n.d.-c; U.S. Dept of Transportation, n.d.-b).

The 95 Expressway utilizes a dynamic, congestion-based pricing system – the toll rate changes based on the amount of traffic in the express lanes (FDOT, n.d.-c). Users are charged for every tolling point they interact with along the facility (see Figure 9) – it is possible to only interact with a single tolling point during a trip (FDOT, n.d.-c). While there is a minimum per tolling point charge, FDOT does not provide a maximum trip charge (FDOT, n.d.-c). The 95 Expressway's system reduces user privacy by collecting travel data at every tolling point along their route rather than at a single entry or exit.

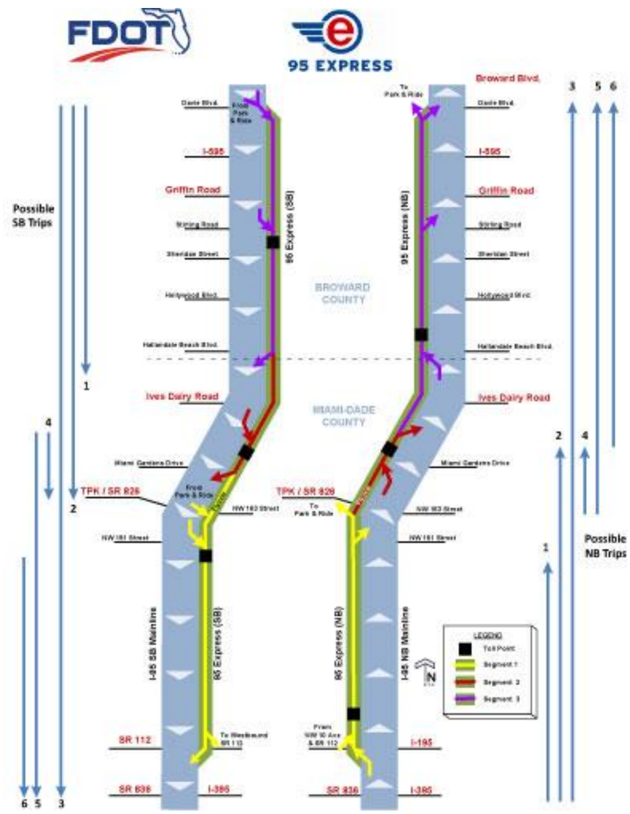

Figure 9: Miami 95 Express Lanes entry and exit points for Phase 1 and Phase 2 (FDOT, 2014).

All tolls are collected using an electronic toll transponder via SunPass[9] (FDOT, n.d.-a). Sunpass offers two transponder options, a more expensive portable hard case, or a cheaper adhesive sticker tag for single-vehicle use (FDOT, n.d.-a). Users can purchase transponders at retail outlets, including groceries and pharmacies across Florida (FDOT, n.d.-a). Emergency vehicles, express buses, vanpools, HOV3+, motorcycles, hybrids, electric vehicles, and other Inherently Low Emissions Vehicles (Hybrids/EVS/LEVS) are exempt from tolls (FDOT, n.d.-b). However, HOV3+ and Hybrids/EVS/LEVS must pre-register for toll-free use (South Florida Commuter Services, n.d.-b, n.d.-a). Providing multiple price points for the transponder and allowing purchase at physical locations makes accessing the 95 Express Lanes more equitable. The exemptions for users reducing emissions or congestion through their mode of transit choices also increase perceived system fairness.

Bus ridership surveys performed pre-deployment, post-deployment of Phase 1A and post-deployment of Phase 1B to gauge mode shift found that conversion from HOV to HOT lanes positively impacted bus transit (Pessaro et al., 2013). Users experienced a travel time savings of 17 minutes and 57% increase in ridership between 2008 and 2010 (Pessaro et al., 2013). Pessaro et al.'s (2013) analysis of the ridership surveys revealed:

> "… that the overwhelming majority (86%) of [95 Expressway] bus riders [had] access to their own vehicle always or most of the time. Furthermore, a full 72% of the passengers could be classified as new riders… Of these new riders, 38% used to drive alone and another 34% switched from Tri-Rail or Metrorail because the express bus was a more direct service. Only 3% indicated that they switched to transit from carpooling" (p. 119).

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[9]Transponders that are also compatible with the 95 Expressway include Florida's OOCEA E-Pass and Lee County LeeWay, the North Carolina Quick Pass, and Georgia Peach Pass.

The South Florida Commuting Services (n.d.-a) also offers a ride-matching portal for drivers in need of carpool partners. Public and active transit, carpool, and vanpool commuters can also register for the Guaranteed Ride Home program, which provides fare coverage for transit costs incurred due to unplanned or emergency situations (South Florida Commuter Services, n.d.-c). Both programs encourage users to utilize alternative transit methods to driving alone by increasing accessibility and simplicity (South Florida Commuter Services, n.d.-c).

Capital costs for Phase 1A and 1B totalled USD$139M (CAD$240.9M) with funding from USDOT Urban Partnership Agreement (UPA) funds, federal funds, and state legislative earmark; transit received USD$19.5M (CAD$33.8M) of the UPA funds (U.S. Dept of Transportation, n.d.-b). Phase 2 cost USD$112M (CAD$185.8M) and was funded through federal stimulus funds and other federal, state, and local funds (U.S. Dept of Transportation, n.d.-b). Finally, Phase 3 cost USD$520M (CAD$808.7M); details about funding sources were not available (U.S. Dept of Transportation, n.d.-b). Early estimates of annual system operating costs were USD$7.5M (CAD$13M) per year (U.S. Dept of Transportation, n.d.-a). Revenue from Phase 1A and 1B totalled USD$5.3M (CAD$9.1M) and USD$6.6M (CAD$11.2M), respectively (U.S. Dept of Transportation, n.d.-a). Lack of data from the system's expansion prevents a clear determination of cost-effectiveness.

3.2.6 Minneapolis (I-394)

The 11-mile conversion of HOV-to-HOT lanes on the I-394 between Wayzata and Minneapolis (I-394 MnPass Express Lanes) in May 2005 was the first of its kind in Minnesota (Minnesota Dept of Transportation, n.d.-a; U.S. Dept of Transportation, 2010c). Figure 10 depicts one eastbound, one westbound, and two reversible lanes created by conversion, as well as tolling entrances and exits (Minnesota Dept of Transportation, n.d.-a). The single-direction lanes are separated from traffic by a double-white-line paint stripe, while a concrete barrier separates the reversible section (U.S. Dept of Transportation, 2010c). The I-394 MnPass Express Lanes were intended to improve the efficiency of high-occupancy lanes, increase their carrying capacity, and help maintain a 45-mph speed for transit and cars in the express lanes (U.S. Dept of Transportation, 2010c). Before implementation, bus and carpool users of the existing HOV lanes strongly opposed the conversion, with 72% and 75% respectively in favour of the lanes remaining as they were (Blake, 2002). On the other hand, 72% of single-occupancy vehicle (SOV) users felt the lanes should be modified or opened to all traffic (Blake, 2002). The MnPass system has received strong public approval, 91% of MnPass enrollees expressed satisfaction with the program, and 84% agreed or

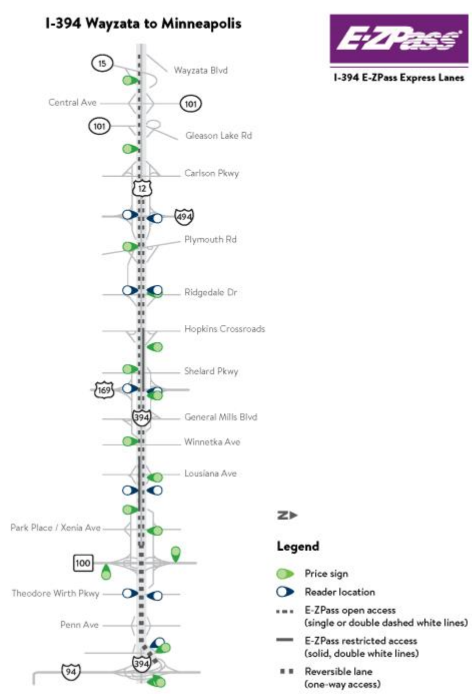

Figure 10: Map of the I-394 MnPass Express Lanes. Green tags indicate pricing signage. Purple tags indicate tolling gantries (Minnesota Dept of Transportation, n.d.-a).

strongly agreed that the lanes provided “a fast, safe reliable commute every time” (U.S. Dept of Transportation, 2010c)[10].

The I-394 MnPass ExpressLanes utilize a dynamic, congestion-based pricing system – the toll rate changes based on the amount of traffic in the express lanes (Minnesota Dept of Transportation, n.d.-c). Charges are enforced during peak commute hours. The eastbound lane only tolls users during morning commute hours (6-10 am), while the westbound lane only tolls users during evening commute hours (3-7 pm); outside of these times the directional lanes are free and open to all traffic (Minnesota Dept of Transportation, n.d.-a). When open, reversible lanes are always tolled (Eastbound 6 am to 1 pm and Westbound 2 pm to 5 am) but are closed to all traffic during the directional transition (Minnesota Dept of Transportation, n.d.-a). Overhead gantries display pricing. The price when the user enters the lane is the price point for the trip, even if the rate changes while they travel (Minnesota Dept of Transportation, n.d.-c). Only capturing travel data upon entry, rather than for the whole trip, improves user privacy.

To utilize the express lanes while tolling is in effect, users must register for an E-ZPass account and have an electronic transponder in their vehicle (Minnesota Dept of Transportation, n.d.-c). Upon registration for an E-ZPass, American Automobile Association (AAA) members can receive a toll credit to their account (Minnesota Dept of Transportation, n.d.-b). The E-ZPass transponder allows users to switch between single occupant and HOV2+ in real-time and is transferrable between vehicles (Minnesota Dept of Transportation, n.d.-c). Transponder transferability provides increased flexibility to users and improves ease of access to the system. Automatic charges are applied to users’ accounts if their balance drops below a minimum threshold. Minnesota E-ZPass users can also use their E-ZPass account funds on participating tolling systems across 19 states (Minnesota Dept of Transportation, 2021). Vanpools, transit, motorcycles, and HOV2+ are exempt from tolls, though HOV2+ are still required to maintain an E-ZPass transponder (U.S. Dept of Transportation, 2010c). The exemptions for users reducing emissions or congestion through their mode of transit choices also increase perceived system fairness.

The U.S. Department of Transportation (2010c) reported that the capital costs for the I-394 MnPass Express Lanes were approximately USD$10M (CAD$19.1M). Operating costs were reported at USD$1.2m (CAD$2M) annually, with revenue of just over USD$1M (CAD$1.7M) annually (U.S. Dept of Transportation, 2010c). State statute strictly defines revenue use, focusing on repaying capital costs, funding operations and maintenance, and finally funding highway and transit improvements (Minnesota Dept of Transportation, n.d.-d). As the I-394 MnPass Express Lanes purpose is to ensure efficient and consistent commute times, emissions reduction data is unavailable. However, usage data shows that during peak commuting times, the express lanes move twice as many people as standard lanes[11] – 80% of which are riding buses or carpooling (Minnesota Dept of Transportation, n.d.-d). Single occupant vehicles compose 22% of lane

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[10] The U.S. Department of Transportation (2010c,d) utilized the same survey data to assess project support for both the I-394 and I-35W HOV-to-HOT conversions as they are part of the overall MnPass system.

[11] The Minnesota Department of Transportation’s usage data is aggregated for all express lanes in their E-ZPass system, which include lanes on the I-394, I-35W (Burnsville to Minneapolis), I-35E, and 1-35W (Roseville to Blaine).

traffic during peak hours, but only 12% of people moved (Minnesota Dept of Transportation, n.d.-d).

3.2.7 Minneapolis (I-35W)

Between 2009 and 2011, the I-35W conversion project changed 16 miles of HOV lanes into HOT lanes between Burnsville and Minneapolis (I-35W MnPass Express Lanes) (Minnesota Dept of Transportation, n.d.-a). The I-13W MnPass Express Lanes consist of two directional lanes (one in each direction), separated from regular traffic by lane striping. Figure 11 depicts the converted lanes and their tolling entrances and exits (Minnesota Dept of Transportation, n.d.-a; U.S. Dept of Transportation, 2010b). The conversion project was part of the Urban Partnership Agreement (UPA) with the U.S. Department of Transportation to reduce congestion, improve and increase transit service attractiveness, and provide transit options for commuters to avoid congestion (U.S. Dept of Transportation, 2010b). Before implementation, bus and carpool users were moderately opposed to the conversion, with 62 and 67% respectively in favour of the lanes remaining as they were (Blake, 2002). Conversely, SOV users were strongly favoured (83%) of modifying or opening the lanes to all traffic (Blake, 2002). The conversion's capital costs for implementation were approximately USD$50M (CAD$86.9M), including roadway improvements and ITS infrastructure (U.S. Dept of Transportation, 2010b).

Figure 11: Map of the I-35W Express Lanes. Green tags indicate pricing signage. Purple tags indicate tolling gantries (Minnesota Dept of Transportation, n.d.-a).

The I-35W MnPass ExpressLanes utilize a dynamic, congestion-based pricing system (Minnesota Dept of Transportation, n.d.-c). Charges are enforced during peak commute hours. The northbound lane contains two tolling sections – before and after the Hwy 62 exit. The northbound lane contains two tolling sections – before and after the Hwy 62 exit. Users are tolled on exits prior to Hwy 62 during morning commute hours only (6-10 am) and on northbound exits after Hwy 62 during morning and evening commute hours (3-7 pm) (Minnesota Dept of Transportation, n.d.-a). The southbound lane also contains two tolling sections – before and after the I-494 exit. Users are tolled on exits prior to I-494 during morning and evening commute hours and are tolled on exits after I-494 during evening commute hours only (Minnesota Dept of Transportation, n.d.-a). Outside these times, the directional lanes are free and open to all traffic (Minnesota Dept of Transportation, n.d.-a). The I-35W Express Lanes utilize the same E-ZPass tolling system as the 1-394 lanes (Minnesota Dept of Transportation, n.d.-d, n.d.-c).

Combined operating costs for the I-394 and I-35W were estimated at USD$2M (CAD$3.4M) annually (U.S. Dept of Transportation, 2010b). The U.S. Department of Transportation (2010c) estimated the revenue of the I-35W Express Lanes alone to be approximately USD$1M (CAD$1.7M) and between USD$2M to $4M (CAD$3.4M to $6.8M) when combined with the I-394 MnPass lanes. State statute strictly defines revenue use, focusing on repaying capital costs, funding operations and maintenance, and finally funding highway and transit improvements (Minnesota Dept of Transportation, n.d.-d).

In addition to lane conversion, transit improvements included new and expanded express bus services, six new or expanded park-and-ride facilities, and the installation of real-time travel signage along the I-35 and for downtown bus routes (Pessaro et al., 2013). These investments improve credible commitment in the system and support users in accessing alternative transit methods. Bus speeds on the I-35W Express Lanes increased by 29 mph northbound and 11 mph southbound (Pessaro et al., 2013). Pessaro et al.'s (2013) analysis of the national longitudinal studies of transit performance in UPA corridors found that between 2009 and 2011, average weekday bus ridership increased by 13%, and 23% of new bus riders reported that the MnPass lanes had influenced them to ride the bus. Pessaro et al. (2013) also found that of the I-35W express bus commuters, 93% have access to at least one vehicle.

3.3 Zonal systems

This section reviews six zonal systems across Paris, Milan (Area B), Lisbon, and London (congestion charge, low emission zone, and ultra low emission zone). Appendix D: Evaluative criteria of zonal pricing systems summarizes the evaluation against the multi-attribute policy framework from Table 1.

3.3.1 Paris

In 2015, Paris established a Low Emission Zone (LEZ) following the perimeter of the A86 ring road (see Figure 12) (City of Paris, 2022). The Paris LEZ covers the City of Paris and extends into Greater Paris. As of 2021, it covered 79 municipalities located in whole or in part within the A86 with a total of 5.61 million inhabitants (Métropole du Grand Paris, n.d.). By implementing a LEZ, the city aimed to reduce air pollutants related to road traffic, decrease concentrations of air

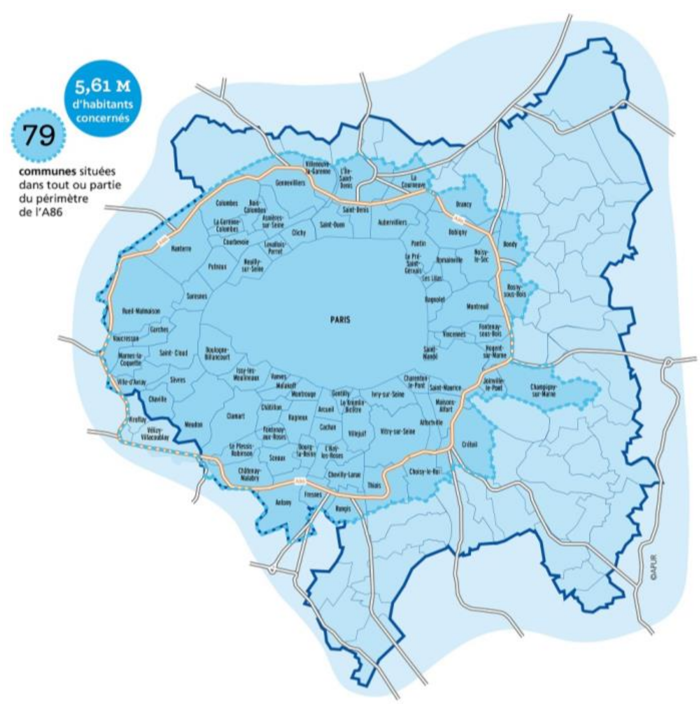

Figure 12: Perimeter of Paris' Low Emission Zone (LEZ). Dotted line indicated the 79 municipalities located in all or part of the A86 perimeter. The solid dark blue line indicates the inhabitants impacted (5.6M) by the LEZ (City of Paris, 2022).

pollutants, reduce the number of people exposed to pollutants above the regulatory values or recommendations of the World Health Organization (WHO), and encourage the use of active transit by gradually restricting the circulation of the most polluting vehicles (City of Paris, 2022). As part of the implementation process, the city conducted prefiguration studies of the zone, developed a draft bylaw, and consulted with inhabitants of the proposed zone and stakeholders (Métropole du Grand Paris, n.d.). After the bylaw was approved and signed into effect, a control was taken so the effectiveness of the system could be evaluated at a minimum every 3 years (Métropole du Grand Paris, n.d.). Since the Paris LEZ's implementation, it has been reinforced three times – first in 2017, again in 2019, and most recently in June 2021; further reinforcements of the zone are planned through 2030(City of Paris, 2022).. Future milestones include traffic restrictions Crit'Air 3 vehicles in 2023, traffic restrictions on Crit'Air 2 vehicles and full compliance with European pollution limit values in 2024, and finally 100% clean vehicles by 2030 and compliance with WHO guidelines for all pollutants (City of Paris, 2022).

A Crit'Air sticker (aka air quality certificate) is required for all vehicles entering the Paris LEZ during restricted travel periods (Ministry of Ecological Transition & Territorial Cohesion, n.d.-b). There are seven classes of Crit'Air, including unclassified vehicles which do not receive a sticker (see Appendix E: Crit'Air classification system for Paris' Low Emission Zone for Crit'Air vehicle classifications) (Poulhès & Proulhac, 2021). Crit'Air classification is determined based upon the combination of a vehicle's fuel type, vehicle type (i.e., passenger, bus, moped, etc.), and EURO standard (Ministry of Ecological Transition & Territorial Cohesion, n.d.-b). Both domestically and foreign registered vehicles must pay a small, flat rate for a Crit'Air sticker; classifications are only purchased once, as they are valid for the lifetime of the vehicle (City of Paris, 2022). Crit'Air stickers are compatible with all LEZ across France (Government of France, 2023; Ministry of Ecological Transition & Territorial Cohesion, n.d.-b). The direct correlation between EURO standards and Crit'Air stickers, lifetime validity of the sticker, and the single zone make Paris' LEZ a very simple system for users to utilize.

The Paris LEZ is restricted to vehicles of Crit'Air 3 or lower from 8:00am to 8:00pm every day for heavy-duty vehicles and the same hours Monday to Friday (except public holidays) for all other vehicles (City of Paris, 2022; CLARS, n.d.-c). Vehicles entering the LEZ without a sticker or with a sticker classed above Crit'Air 3 are subject to a flat-rate fine (Government of France, 2023). Crit-Air certification is currently manually enforced by local police; however, the government is looking to transition to camera enforcement (CLARS, n.d.-c). Current reliance on manual enforcement, rather than traffic cameras, increases user anonymity within the system as well as associating the Crit'Air sticker with the vehicle rather than the owner.

Between 2010 and 2016, concentrations of NO_x, NO_2, PM_{10}, and $PM_{2.5}$ on roads within the LEZ showed a downward trend between 1.9 and 6.6% annually (Font et al., 2019). France's overall air quality has also shown distinct improvement with regulations to polluting sectors, in particular transportation, resulting in European Union regulatory air quality standards for NO_2, PM_{10} and O_3 to be exceeded less often than in the past (Ministry of Ecological Transition & Territorial Cohesion, 2018). In addition to the LEZ, Paris has implemented overlapping climate policies which may increase the impact of the LEZ as well as be responsible for some of the emissions abatement in the restricted zone. Multiple programs to support users in transitioning to a new mode of transit are available. Individuals can receive significant rebates when purchasing a new or used ZEV, 2-wheeler, 3-wheeler, electric quadricycle, or electric assisted bike

(Métropole du Grand Paris, n.d.). Individuals located within the LEZ are eligible for an additional rebate (Ministry of Energy Transition, 2023). Dedicated carpooling areas have also been implemented at the gates of Paris; as of 2019, approximately 100 self-service vehicles were available for use by professionals (City of Paris, 2019). The City of Paris (2019) has also focused on urban planning to support active transit, implementing a Bike Plan and a Pedestrian Plan intended to reorganize the public space in favour of cycling and walking. Public transport has also received investments and financial aid is available for users looking to utilize public transport in their commute (City of Paris, 2019). The significant investment in both financial and infrastructure programs to promote mode shift, as well as the low financial barrier to entry for individuals who already meet the LEZ vehicle standards helps to reduce potential equity impacts from the system and improve accessibility.

3.3.2 Milan (Area B)

After Italy was referred to the European Court for non-compliance and exceedances related to PM10 and NO2 in May 2018, Milan implemented a LEZ (Area B) in February 2019 to address the most-polluting vehicles (C40 Cities Climate Leadership Group & Nordic Sustainability, 2019; Municipality of Milan, 2022a). Prior to implementation, the proposal was compared against existing systems across Europe including Paris, Berlin, Brussels, and Barcelona; the Mobility and Environment Department found that the system would be most like Brussels' (Municipality of Milan & Mobility and Environment Department, 2019). There was a distinct focus on effectiveness, equity, and transparency in the system design process (Municipality of Milan & Mobility and Environment Department, 2019). In defining an equitable system, Area B focused on consistent application of the system to various types of users (i.e., reducing occasional access and system exemptions) (Municipality of Milan & Mobility and Environment Department, 2019).

Figure 13: Map of Milan's Area B. Single red line indicates zone's boundary. Coloured dots indicate electronic tolling gate - different colours indicate the different phases in which gates were installed (Municipality of Milan & Mobility and Environment Department, 2019).

Area B covers 75% of the city and is demarcated by 186 access gates (C40 Cities Climate Leadership Group & Nordic Sustainability, 2019; Municipality of Milan, 2023). The system is very simple for users to access. The zone is active Monday to Friday from 7:30 to 19:30 (excluding holidays) and there is no cost to enter for approved vehicle types; all other vehicles must enter outside of the designated hours (Municipality of Milan, 2022c, 2023). Tracking of vehicle entry to Area B was a multi-phase process that included the installation of entry signage and 187 electronic gates (as depicted in Figure 13) (Municipality of Milan & Mobility and Environment Department, 2019). Camera enforcement is used to ensure only vehicles that meet emissions requirements are entering Area B during restricted periods; violators are subject to a flat fine (Municipality of Milan, 2023). As the system is free, users do not have to register to access Area B making it more anonymous than facility-based and cordon systems; however, user privacy is still somewhat impacted by camera monitoring at access gates.

Vehicle emissions requirements in Area B have become progressively more stringent since its inception and are planned to progressively increase through 2030 until all diesel and Euro 6 vehicles are banned (C40 Cities Climate Leadership Group & Nordic Sustainability, 2019; CLARS, n.d.-b). Table 3 shows the specific Euro environmental classes able to enter the zone during restricted hours as of October 2022; hybrid and electric vehicles may enter Area B unrestricted (CLARS, n.d.-b; Municipality of Milan, 2023). The exemptions for users who are reducing emissions through their mode of transit choice also increase perceived system fairness.

Table 3: Vehicle types able to enter Area B during restricted traffic periods (CLARS, n.d.-b).

	Cars	**Commercial vehicles**	**Mopeds/motorcycles**
Petrol	Euro 3	Euro 1	Euro 2
Diesel	Euro 6	Euro 5	N/A
2-stroke	N/A	N/A	Euro 2

Milan has been closely tracking the emissions reductions in Area B since the LEZ's implementation. Both PM_{10} and NO_x have seen steady rates of decline and are anticipated to continue declining; PM_{10} emissions were reduced by half (15 tonnes) in the first 4 years (Municipality of Milan, 2022a). Individuals who already meet the vehicle emission criteria have a very low barrier for entry, as the LEZ has no entry fee; however, there are no financial programs available to support individuals seeking to transition to alternative transit. Milan has planned for investments in public transit expansion projects – €25M (Cad$37.9M) per year between 2019 and 2021 and €120M (Cad$160.2M) per year between 2022 and 2024 (Municipality of Milan & Mobility and Environment Department, 2019). Investments included line extensions, upgrades, and improved frequency across trams, subways, and buses (Municipality of Milan & Mobility and Environment Department, 2019). Infrastructural investments can improve the accessibility of existing transit options for individuals who cannot afford to transition to a cleaner vehicle but may still need to access Area B. Between 2019 and 2022, Milan regularly offered publicly funded vehicle replacement opportunities to both businesses and residents of Area B. For residents, these included rebates on between 20 and 60% of the vehicle cost depending on the vehicle type, overall cost, and environmental class (Municipality of Milan, 2022b). Rebates improve system equity by reducing the barrier for users to shift their mode of transit to one that incurs lower or no fees.

3.3.3 Lisbon

In 2008 EU establishment of limits for pollutants including PM_{10}, $PM_{2.5}$, NO_2, and NO_x; Lisbon frequently exceeded these limits with the city's automobile traffic contributing significantly to air quality pollution (F. M. Santos et al., 2019; Silva et al., 2014). To address frequent exceedances, Lisbon implemented a LEZ in July 2011 as part of its Air Quality Action Plan (Ferreira et al., 2015; F. M. Santos et al., 2019). The LEZ is also supported by statutory legislation for controlling air pollution (Lisbon City Council, 2021; Silva et al., 2014). Prior to implementation, the city conducted a traffic study to "characterize the origin and volume of pollutant emissions" (Silva et al., 2014, p. 134). The taxi fleet, particularly older vehicles, were found to contribute the most emissions for their category (almost 1/3) despite only making up 17% of light vehicles (Silva et al., 2014).

The LEZ was introduced in three phases, staggering the implementation of the two restricted zones (see Figure 14) and gradually increasing the stringency of vehicle emission requirements (F. M. Santos et al., 2019). Zone 1 is only 0.6 sq km in size and contains three authorized crossing points to connect the hills across Lisbon's downtown (Silva et al., 2014). Phase 1 of implementation restricted the travel of below a EURO 1 rating in Zone 1 on weekdays between 8am and 8pm (F. M. Santos et al., 2019). Phase 2 began in April 2012 increasing the restriction area to include Zone 2 which was significantly larger (26 sq km) than Zone 1; the restriction period also increased to 7am to 9pm (F. M. Santos et al., 2019; Silva et al., 2014). The minimum standard for Zone 1 increased to EURO 2 vehicles and in Zone 2 pre-EURO vehicles were restricted. In January 2015, the final phase began, increasing the vehicle emission stringency for both zones (F. M. Santos et al., 2019). Zone 1 required a minimum emission requirement of EURO 3, while Zone 2 required a minimum emission requirement of EURO 2 (F. M. Santos et al., 2019).

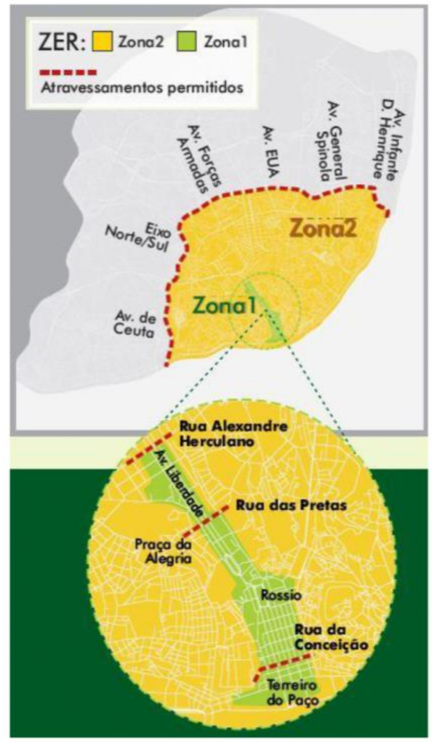

Figure 14: Map of Lisbon's LEZ. Green shaded area depicts Zone 1. Yellow shaded area depicts Zone 2. Red dotted lines indicate authorized crossing points (Silva et al., 2014).

To enter the LEZ, users must register via the city's online portal and display the provided sticker on their vehicle; there is no cost to participate (Lisbon City Council, 2021). People with limited mobility, certain residents, taxis active between January 15 and June 30, 2015, natural gas vehicles, liquefied petroleum gas (LPG) vehicles, motorcycles, and emergency vehicles are exempt from Phase 3 restrictions (Lisbon City Council, 2021). These exemptions increase perceived fairness which is necessary for achieving public acceptability. Enforcement of Zone 1 was initially performed manually by the Lisbon police; however, the police's scarce resources and Zone 2's significantly larger size required the utilization of pre-existing traffic cameras, authorized by Portugal's National Data Protection Commission (Silva et al., 2014). While the use of camera enforcement does somewhat reduce user privacy, the stickers are not providing real-time travel data to the city or a third-party – unlike transponders.

Lisbon's LEZ has resulted in significant emissions reductions and helped the city meet several of its legislated emissions goals. F.M. Santos et al. (2019) found that between 2009 and 2016, Zone 1 saw the annual average concentration of PM_{10} and NO_2 reduce 29% and 12% respectively. In Zone 2, annual average concentrations for the same air quality emissions reduced 23% and 22%. The LEZ didn't have a significant impact on the annual average concentration of $PM_{2.5}$; however, the average levels also remained within legislated limits (F. M. Santos et al., 2019).

F.M. Santos et al. (2019) also observed some limited reductions in NO_x, but they were not great enough to bring annual average concentrations in line with legislated limits. Lisbon also supports free public transit passes for young people and students ages 13 to 23 and seniors aged 65 and over, offering an alternative to driving in these restricted zones (Lisbon City Council, n.d.).

3.3.4 London (LCC)

To combat pollution and inner-city traffic, the Greater London Authority has implemented progressively more stringent, overlapping congestion pricing systems over the last two decades. This section will discuss the earliest system, the London Congestion Charge (LCC) while the next section will discuss the later development of London's LEZ and the Ultra Low Emission Zone (ULEZ). The boundaries of all three systems can be seen in Figure 15. In February 2003, the London Congestion Charge (LCC) was the first congestion pricing system implemented – covering 21 sq km of the city center (Croci, 2016; Lehe, 2019). Prior to the LCC's introduction, there were six years of parliamentary deliberation on the matter of road pricing, the passage of the Greater London Authority Act in 1999 – creating the Greater London Authority which gave London's mayor broad power over the city's transportation, an expert study performed by the Road Charging Options for London (ROCOL) working group – published March 2000, and finally public consultation (Lehe, 2019). The capital cost to implement the LCC was approximately £160 million (Croci, 2016). Annual operating costs were around 90 million, bringingan average gross revenue of £182.5 million each year (Croci, 2016). An attempt to extend the LCC was made in 2004 but was ultimately abandoned due to low public support (Lehe, 2019).

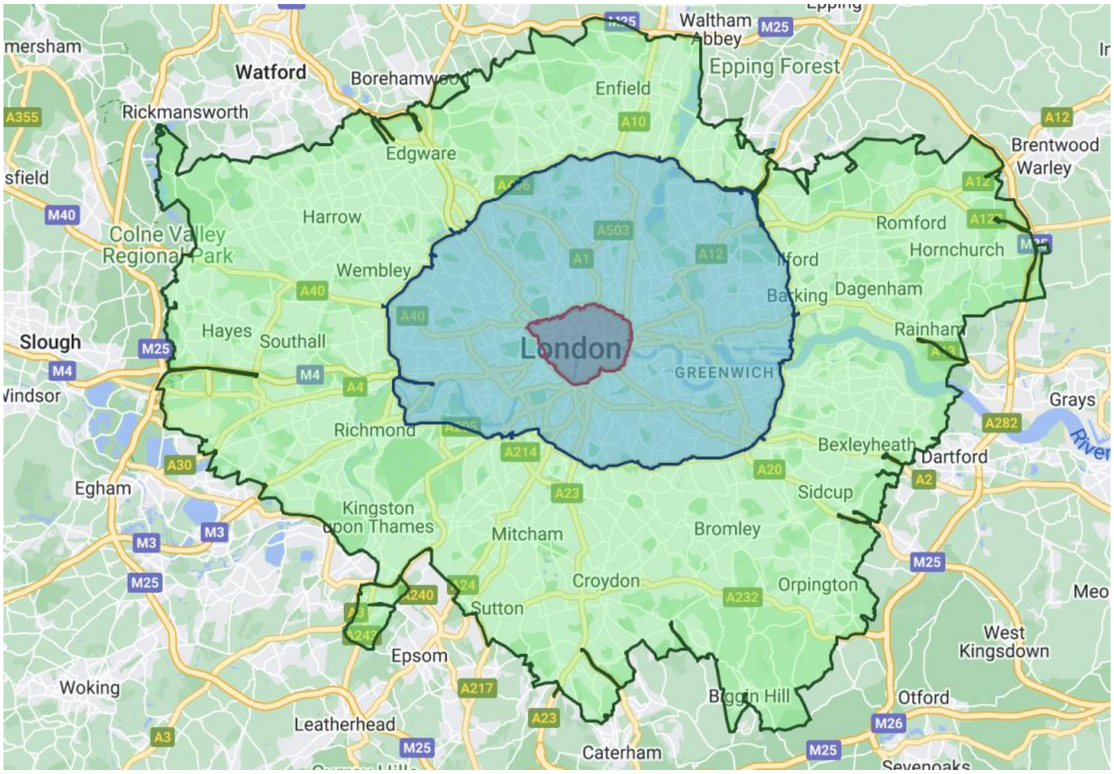

Figure 15: Map of the London emission restriction zones. The green area indicates the LEZ, blue the ULEZ, and red the LCC. These zones overlay one another, creating three overlapping zones (TfL, n.d.-f).

The LCC is active Monday through Friday from 7am to 6pm and weekends (including bank holidays[12]) from noon to 6pm (TfL, n.d.-f). There is a flat daily fee to enter, exit or travel within the LCC (Croci, 2016; TfL, n.d.-a); enforcement is managed using cameras (Croci, 2016). TfL offers an online portal where users can pay in advance, by midnight of the third day after travel, or set up auto-pay which automatically charges the payment at the end of each month (TfL, n.d.-a). A mobile application is also available to allow users to pay their fees directly from their phones (TfL, n.d.-a). Residents of the LCC receive a 90% discount. Blue badge holders[13], accredited breakdown vehicles and roadside recovery vehicles, vehicles with nine or more seats, cleaner vehicles, and motor tricycles at maximum one metre wide and two metres long are all eligible for a 100% discount as long as a £10 registration fee[14] is maintained (TfL, n.d.-b). In addition to the discounted groups, two wheeled motorbikes and mopeds, taxis (not including private hire vehicles), emergency service vehicles including tax-exempt NHS vehicles, and tax-exempt vehicles used by individual disabled people and for transporting more than one disabled person (i.e., dial-a-ride) are exempt from the fee and do not need to register with Transport for London (TfL). Failure to pay for travel within the LCC can result in sliding-scale penalty fees (TfL, n.d.-h).

[12] The LCC does not charge users in the period between Christmas Day and New Year's Day bank holiday.
[13] Disabled motorists or motorists who care for a disabled person.
[14] Registration fees are either renewed annually or in line with an associated document's expiry (i.e., Blue Badge)

The implementation of the LCC resulted in an initial reduction of GHG and air quality emissions within the zone; however, these reductions were short-term as congestion levels increased after 2006 (TfL & Mayor of London, 2008). The TfL attributed any continued emissions reductions within the zone to year-over-year fleet improvements (TfL & Mayor of London, 2008). The LCC averages 43,554 charges per day (TfL, 2022a). The LCC's introduction in 2003 contributed to a significant year-over-year increase in bus ridership – it was responsible for approximately half of the increase in bus riders between 2002 and 2003 (TfL & Mayor of London, 2008). As a result, most net revenues were allocated back to bus operational measures (TfL & Mayor of London, 2008). By 2007, impacts to bus ridership were more modest between 6 and 9% (TfL & Mayor of London, 2008).

3.3.5 London (LEZ & ULEZ)

The second of London's systems to be implemented was the LEZ which addressed London's air quality – some of the poorest in Europe (Deloitte, 2005; Ku et al., 2020). Prior to implementation, feasibility studies were conducted in 2003 and 2005 regarding the operation, enforcement, implementation, and emission standards for an LEZ (Deloitte, 2005). The LEZ was ultimately phased into use beginning in 2008 (Ku et al., 2020). In April 2019, London implemented the Ultra Low Emission Zone (ULEZ) to address continued NO_2 and PM concerns; the ULEZ was expanded significantly in October 2021 and now covers approximately 4 million people (Ku et al., 2020; Mayor of London, 2022). The LEZ and ULEZ are integrated with LCC through a shared online payment portal (TfL, n.d.-e).

The LEZ operates all day, every day including holidays; minimum emission standards are only set for HGVs (TfL, n.d.-f, n.d.-m). Lorries, vans, and specialist heavy vehicles over 3.5 tonnes gross vehicle weight (GVW) as well as buses/minibuses and coaches over 5 tonnes GVW must be at minimum EURO 6 (both NO_x and PM) (TfL, n.d.-m). Vans and specialist diesel vehicles between 1.205 tonnes unladen weight and 3.5 tonnes GVW as well as minibuses up to 5 tonnes GVW must be at minimum EURO 3 (TfL, n.d.-m). Foreign vehicles must also register in TfL's online system to ensure they meet these standards and do not face penalty charges while travelling in the LEZ (TfL, n.d.-m). HGVs can still travel within the LEZ if they do not meet the minimum emission standards; however, they must pay a flat daily fee based on the vehicle's EURO emission standard (TfL, n.d.-e). A limited number of vehicles are exempt from the LEZ including certain agricultural vehicles, vintage/historic vehicles, and vehicles operated by the Ministry of Defence; foreign vehicles must be registered with the TfL to receive an exemption (TfL, n.d.-d). Showman's vehicles can also receive a 100% discount provided they register with the TfL, this applies to both U.K. and foreign vehicles (TfL, n.d.-d).

The TfL (n.d.-l) recommends that individuals and companies operating HGVs within the LEZ take steps to meet emission standards including replacing their vehicles, retrofitting vehicles, or reorganizing their fleet so only vehicles which meet emissions standards operate within the LEZ. To support operators looking to retrofit their vehicles, the government provides a Clean Vehicle Retrofit Accreditation Scheme (CVRAS) which connects operators with certified retrofit technology suppliers to ensure modifications meet emission standards (TfL, n.d.-l). While CVRAS improves knowledge and access to certified materials, it does not provide financial incentives or support, reducing its efficacy as an equity measure.

The ULEZ operates all day, every day except for Christmas Day and overlaps the LEZ (TfL, n.d.-f). It is free to enter for vehicles that meet the minimum emission standards (TfL, n.d.-j):

- Motorcycles, mopeds, motorized tri- and quadricycles (L category), EURO 3,
- Petrol cars, vans, minibuses and other specialist vehicles, Euro 4 (NOx), and
- Diesel cars, vans and minibuses and other specialist vehicles, Euro 6 (NOx and PM).

Vehicles that do not meet the minimum emission standards can still enter the ULEZ; however, they must pay a flat daily fee (TfL, n.d.-g). HGVs impacted by the LEZ's EURO 6 minimum standard do not need to pay ULEZ charges, only LEZ charges, if their vehicle does not meet emission standards (TfL, n.d.-j). Fees must be paid within three days of travel in the ULEZ via TfL's online portal or mobile app; users can also register for autopay (TfL, n.d.-f). A variety of temporary discounts, reimbursements, and exemptions exist for the ULEZ particularly supporting users with acute illness and disability, taxis, and community transport vehicles (a complete list of exemptions can be found in Appendix F: Vehicles eligible for discount or exemption from the London ULEZ)(TfL, n.d.-c).

If a user does not have an exemption, does not meet the minimum emission standards, and fails to pay the daily fee for travelling in the ULEZ, they will face a penalty fee (TfL, n.d.-i). However, both the LEZ and the ULEZ see significant vehicle compliance. Within six months of implementation, on average 94% of vehicles travelling within the ULEZ met emission standards; for the LEZ compliance doubled between 2017 and 2021 from 48 to 96% (Greater London Authority, 2021). Of vehicles that don't meet emission standards, on average 879,533 enter the ULEZ each month (TfL, 2022b). To support users in transitioning to lower-emitting transit options, TfL has partnered with businesses to offer Londoners discounts on the rental and financing of bicycles, e-bikes, e-scooters, cars, vans, and e-motorcycles as well as car club membership (i.e., zip car) (TfL, n.d.-k). A government electric vehicle grant is also available to support the purchase of low-emission vehicles (TfL, n.d.-k).

Data regarding vehicle compliance and emission reduction is available for both the LEZ and ULEZ. The Greater London Authority (2021) reported that between 2008 and 2013 the LEZ contributed directly to a 20% reduction in PM_{10} emission concentrations and indirectly to a 27 and 25% reduction in $PM_{2.5}$ and NO_x emission concentrations respectively. Further reductions in NO_2 emission concentrations were reported with the implementation and expansion of the ULEZ; at roadside data points in the zone an estimated 20% reduction and 44% in Central London (Mayor of London, 2022). However, the ULEZ's reductions may be much more modest. Ex-post causal analysis of air quality improvements in the ULEZ found that emission concentration changed between -9 to 6% for NO_2, -5 to 4% for O_3, and -6 to 4% for $PM_{2.5}$ (Ma et al., 2021).

3.4 Comparative results by evaluative attribute

This section reports on the project results in a comparative manner, observing patterns across congestion pricing system types. Comparison of design characteristics in this manner has previously been limited as studies focused on a single design type.

3.4.1 Implementation context

The content analysis has found that the types of activities pursued by local governments when implementing a congestion pricing system vary based on the system type (Table 4). Overwhelmingly, facility-based systems favor public consultation and stated preference surveys to assess acceptability and user mode shift while zonal systems favor professional studies to assess overall system effectiveness. These engagement approaches address different aspects of successful system implementation. Public consultation and the scope of stated preference surveys are limited during the pre-implementation period, as public perception of congestion pricing systems is consistently higher post-implementation (see Section 4.4 below). While important for building credible commitment and establishing data baselines, decision-makers should utilize additional activities to collect broader pre-implementation data. Professional studies are particularly useful for establishing baseline emissions data and mode of transit data, as seen with Lisbon, London, and Paris systems. Trial periods address user uncertainty through system familiarity (Gu et al., 2018) particularly, for more complex systems – such as Stockholm's time-variable cordon – trial periods can mean the difference between a referendum passing or failing.

Table 4: Activities pursued by local governments during the congestion pricing system implementation process organized by system type.

City	System type	Date implemented	Trial period	Referendum/ bylaw	Professional study	Public consultation/survey
Milan (EcoPass)	Cordon	2008			✓	✓
Milan (Area C)	Cordon	2012	✓			
Stockholm	Cordon	2010	✓	✓		✓
Melbourne	Facility	2008				✓
Atlanta	Facility	2011				✓
Denver	Facility	2006				
Houston	Facility	2000				
Miami	Facility	2008				✓
Minneapolis (I-394)	Facility	2005				✓
Minneapolis (I-35W)	Facility	2009				✓
Paris	Zonal	2015		✓	✓	✓
Milan (Area B)	Zonal	2019				
Lisbon	Zonal	2011			✓	
London (LCC)	Zonal	2003			✓	✓
London (LEZ)	Zonal	2008			✓	
London (ULEZ)	Zonal	2019			✓	

Both Stockholm and Paris' systems stand out for their thorough implementation processes. Stockholm's use of a trial period takes an active approach to reducing public uncertainty with the new congestion pricing system rather than only assessing public sentiment through a survey. Utilizing a public referendum allowed the government to gauge public acceptability of the system while supporting citizen involvement in the policy process. In the case of Paris' LEZ, the combined use of a professional study and a thorough consultation period supported the public in understanding the congestion pricing system, its potential benefits and drawbacks, and gave space for critical feedback to improve public acceptability. Utilizing familiar policy processes like bylaws to frame congestion pricing systems helps reduce public uncertainty with the change. It should be noted that Melbourne also utilized a consultation process like Paris' to implement the Eastlink tollways which utilized a comprehensive information campaign to engage with the community and address concerns (State Government of Victoria et al., n.d.).

3.4.2 Privacy

Cordon and zonal systems have a significantly lower impact on user privacy than facility-based systems (see Table 5). There are minimal, if any, registration requirements for cordon and zonal systems, and camera enforcement is generally applied at designated entry points along the boundary of the cordon/zone. Registration to a payment system is required to participate in most facility-based systems and increases the amount of personal information collected but also has unintended consequences for user equity (see Section 4.3.3 on equity impacts for further discussion).

Table 5: Enforcement methods by system type and city.

City	System Type	Date Implemented	Manual	Camera	Transponder	Registration
Milan (EcoPass)	Cordon	2008	x	✓	x	x
Milan (Area C)	Cordon	2012	x	✓	x	x
Stockholm	Cordon	2010	x	✓	x	x
Melbourne	Facility	2008	x	✓	✓	Optional
Atlanta	Facility	2011	x	✓	✓	✓
Denver	Facility	2006	x	✓	✓	Optional
Houston	Facility	2000	✓	x	✓	✓
Miami	Facility	2008	x	✓	✓	✓
Minneapolis (I-394)	Facility	2005	✓	x	✓	✓
Minneapolis (I-35W)	Facility	2009	✓	x	✓	✓
Paris	Zonal	2015	✓	x	x	x
Milan (Area B)	Zonal	2019	x	✓	x	x
Lisbon	Zonal	2011	✓	✓	x	✓
London (LCC)	Zonal	2003	x	✓	x	Some vehicles
London (LEZ)	Zonal	2008	x	✓	x	Some vehicles
London (ULEZ)	Zonal	2019	x	✓	x	Some vehicles

Reducing the collection of user travel data is important to managing user privacy. Manual enforcement ensures the least amount of data is collected; however, it is not sustainable for larger systems. To address this, systems may use a combination of both manual and camera enforcement (i.e., Lisbon). Where camera enforcement is applied has a major impact on how much it infringes upon user privacy. When cameras are used to enforce an entire zone (i.e., London LEZ) facility users are exposed to greater surveillance and need stronger protections for their travel data. Some facility-based systems have taken small steps to reduce data collection by only charging users when they enter the facility (i.e., Denver, Houston, Minneapolis); rather than track user transponder usage for the duration of their trip, transponders are only charged once.

3.4.3 Simplicity

Facility-based systems are consistently more complex in their charging methods than cordon and zonal systems – most notably due to their high usage of dynamic pricing tied to facility congestion levels (see Table 6). Dynamic, congestion-based pricing makes it difficult for users to predict how much a trip using the facility will cost in advance of travel. While variable, time-of-day pricing provides somewhat more consistency through a pricing table – many of these can be difficult to navigate and have multiple mitigating factors (i.e., season, type of trip) which can increase user uncertainty regarding cost of travel. Several facility-based systems utilize reversible lanes which add another layer of complexity deterring users from participating.

Table 6: Congestion pricing method by system type and city

City	System Type	Rate Type	Time-of-Day	Congestion-based	Emission-based	Distance-based	Other
Milan (EcoPass)	Cordon	Fixed			✓		
Milan (Area C)	Cordon	Fixed					✓
Stockholm	Cordon	Variable	✓				
Melbourne	Facility	Variable				✓	✓
Atlanta	Facility	Dynamic		✓			
Denver	Facility	Variable	✓				
Houston	Facility	Variable	✓				
Miami	Facility	Dynamic		✓			
Minneapolis (I-394)	Facility	Dynamic		✓			
Minneapolis (I-35W)	Facility	Dynamic		✓			
Paris	Zonal	One-time Fee			✓		
Milan (Area B)	Zonal	Free			✓		
Lisbon	Zonal	Free			✓		
London (LCC)	Zonal	Fixed					✓
London (LEZ)	Zonal	Free*			✓		
London (ULEZ)	Zonal	Free*			✓		

Zonal systems offer the lowest barrier to entry for users, offering no, low, or limited fees and utilizing clear EURO vehicle emission standards as the basis for entry. Users unfamiliar with the EURO system can easily access online tools to determine if their vehicle meets the entry criteria. However, the London LCC, LEZ and ULEZ struggle with vaguely defined borders and an overlapping layout which can be difficult to navigate for users who may need to pay fees within one or more zone. Many cordon and zonal systems avoid this problem by requiring users to enter restricted areas through designated access points, simplifying the access process and reducing the chance of accidental entry. It should be noted that both the London LCC and Milan – Area C have taken steps to simplify their charging scheme by reducing the number of rate types to better fit the system usage and applying discounts and exemptions (i.e., resident, commercial, general).

3.4.4 Revenue use

Revenue recycling was most common among cordon and zonal systems with fee structures. Area-based systems had a much stronger focus on recycling revenue into transit improvements than facility-based systems. However, most of these systems did not report on mode shift. The most significant mode shift to bus transit due to congestion pricing system implementation is seen in the London LCC. Half of new bus ridership between 2002 and 2003 was attributed to the LCC and revenue was recycled back into bus operations to accommodate the growing demand (TfL & Mayor of London, 2008). Facility-based systems overwhelmingly lacked long-term revenue recycling schemes – only the two Minneapolis HOT lanes had clearly outlined revenue recycling guidelines. Their state guidelines prioritized road infrastructure improvements before transit improvements. However, many made short-term commitments to transit improvements (i.e., park-and-ride development, express bus expansion). Miami's Express Lanes most notably saw a 57% increase in ridership between 2008 and 2010. During early phases of the system's implementation, Miami committed significant funding to transit expansion and has since developed additional tools to improve users' access to transit other than single-occupancy ridership. Atlanta and Minneapolis (I-394) saw much more modest increases in bus ridership (13%) but offered no significant funding or revenue recycling to transit. Significantly, Houston and Denver's systems are integrated with park-and-ride facilities but did not see significant user mode shift to either bus or HOV (Goel & Burris, 2012; U.S. Dept of Transportation, 2010d).

3.4.5 Emissions abatement

GHG and air quality emissions reporting was highly variable across congestion pricing systems with each jurisdiction reporting on the emissions of greatest concern to them. While not all local governments reported emissions abatement, of those that did changes were reported either as the average change in annual emissions concentrations or as the total percent difference in emissions concentrations between a baseline and a later year (see Figure 16 and Figure 17). Emissions reporting was often determined by pre-existing concerns about air quality in the region. As a result, there was significantly more reporting on air quality emissions than GHG emissions. International disciplinary measures were strong drivers for the implementation of cordon and zonal systems (i.e., Lisbon, Milan – Area C) for the purpose of emissions abatement including both the 2008 European Commission limits on air pollution levels and WHO regulations and recommendations for emissions exposure.

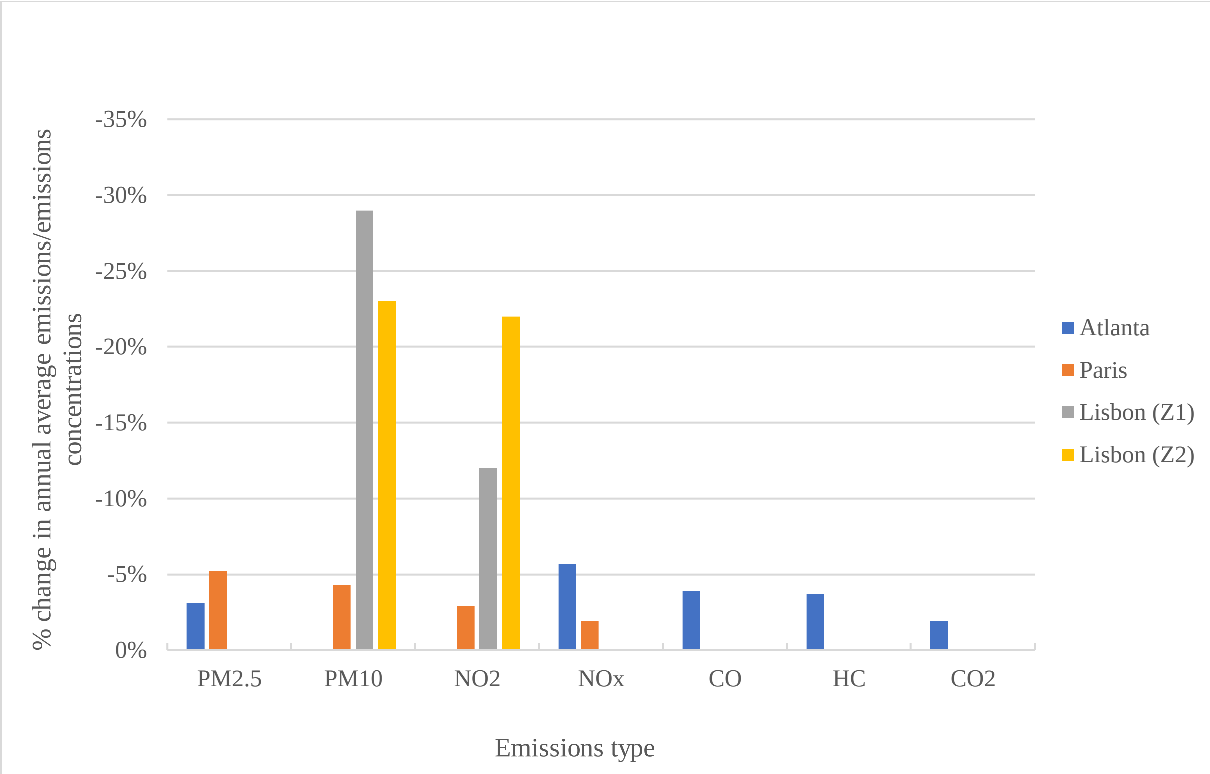

Figure 16: Average change in annual GHG and air quality emission concentrations in congestion pricing systems by emission type. Note that systems were implemented over a broad time period, hence, the comparisons do not consider any overlapping climate policies which may have been implemented concurrently. While this data comes from a variety of sources, emissions abatement results are focused within the priced area or the area and its immediately adjacent streets (Font et al., 2019; F. M. Santos et al., 2019; Xu et al., 2017).

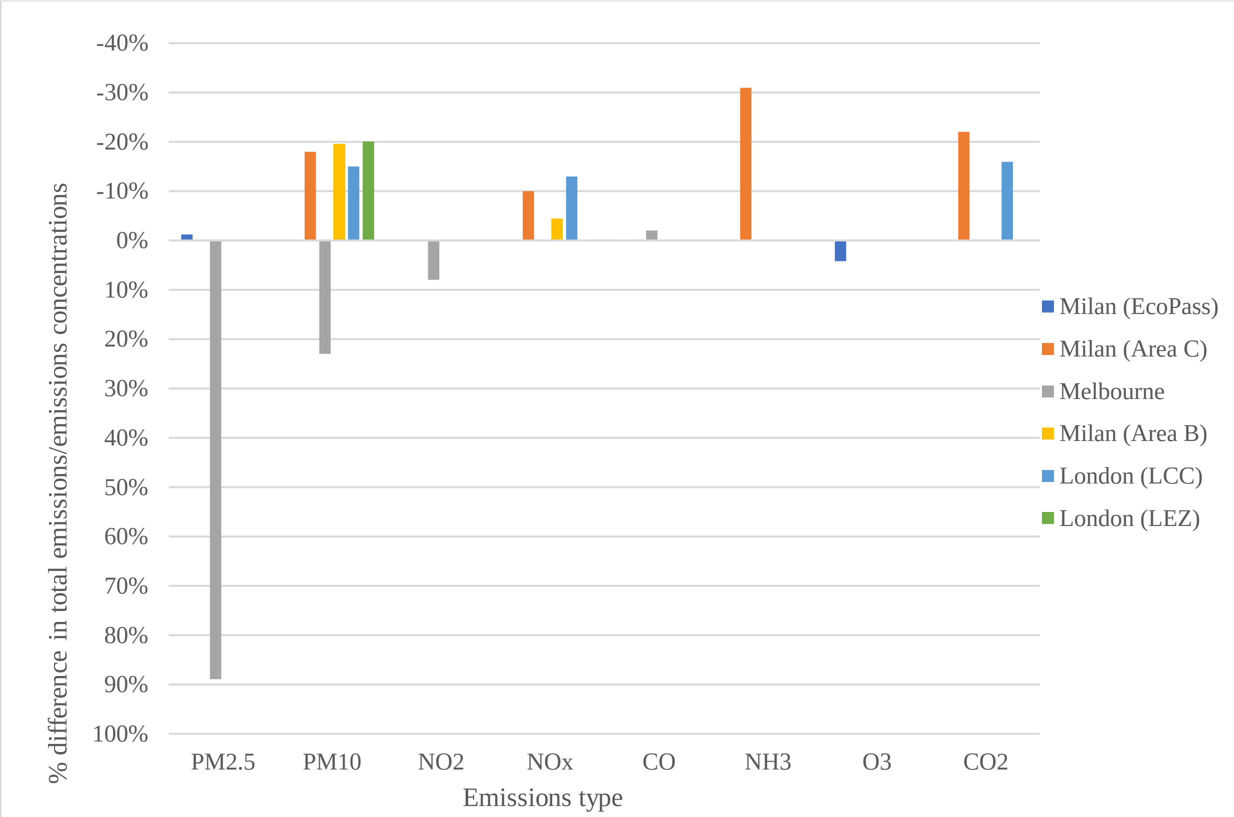

Figure 17: Difference in total GHG and air quality emission concentrations in congestion pricing systems by emission type. Note that systems were implemented over a broad time period and these comparisons do not consider any overlapping climate policies which may have been implemented concurrently. While this data comes from a variety of sources, emissions abatement results are focused within the priced area or the area and its immediately adjacent streets (Beria, 2016; EastLink, n.d.-d; Greater London Authority, 2021; Rotaris et al., 2010; TfL & Mayor of London, 2008)

Cordon and zonal systems reported most consistently on emissions abatement. Across the measured systems, PM_{10} emissions – which are air quality emissions – were most positively impacted by the implementation of an area-based congestion pricing system; NO_2 and NO_x also saw some reductions. CO_2 emissions also saw some reductions from the implementation of area-based congestion pricing systems; however, jurisdictions included data on GHG emissions less consistently making correlation difficult. The analysis was unable to make conclusions about the impact on O_3 emissions, as only one jurisdiction reported data on this emission. Of the facility-based systems which reported on emissions abatement, changes were small or overtly negative. Very few facility-based systems reported emissions abatement making correlation difficult; comparison between area- and facility-based systems in this area should be limited. For example, while Melbourne's emissions impact upon implementation was quite negative, more recent data shows small but regular reductions (EastLink, n.d.-d). More research is needed on the difference pre-existing infrastructure may play in impacting the effectiveness of pricing systems, particularly around emissions abatement.

Surprisingly, Paris' LEZ saw relatively small reductions in annual average emission concentrations despite its robust suite of alternative transit options. More research is needed to determine if this is due to local governments only tracking a limited number of emission types, a relatively high initial air quality, or other factors. Lisbon's LEZ saw some of the greatest air quality emissions abatement from their congestion pricing system; however, it should be considered that Lisbon's air quality began in very poor condition. The cities that saw the greatest abatement results both in annual emissions concentrations and total percent difference over time were Lisbon, London, and Milan – all European cities with a history of air quality concerns.

3.4.6 Net revenue

Zonal systems like Paris and Lisbon which are free of charge to users, rely on pre-existing infrastructure (either manual or camera enforcement), and may require a one-time sticker to improve ease of enforcement are the most cost-effective systems. Most of the administration is focused on one-time registrations (in systems which require this) and enforcement. There is also no cost for the installation or upkeep of control point equipment as these zones can be moved into and out of freely by users. Of congestion pricing systems that charge user fees, we find that cordon systems and newer systems are generally more cost-effective (see Figure 18). Facility-based systems have quite a low rate of return despite their focus on reducing congestion through user fees. Their low net revenue may be influenced by the high cost of implementing and maintaining facilities, the complex administration process associated with managing variable payments, and maintaining adequate enforcement. The simpler cordon systems make significantly more in average annual net revenue than facility-based systems despite having fewer charging rates and more discount and exemption opportunities. Stockholm is the exception, as its fixed, time-variable charging is more like facility-based systems. System size may be another confounding factor in determining cost-effectiveness, as all the cordon systems cover significantly more area than the facility-based systems which are limited to approximately 10 to 20 miles of highway.

Figure 18: Average annual net revenue of congestion pricing systems by jurisdiction and system implementation year. Net revenue has been brought a consistent value in CAD$2020.

3.4.7 Equity impacts

Pre- and post-implementation stated preference surveys have been particularly useful in assessing potential equity impacts from the system (Altshuler, 2010; Axsen & Wolinetz, 2021; Franklin, 2012). Atlanta's I-85 Express Lanes exemplify the unintended negative impacts of facility-based HOT lanes including pricing out low-income users and deterring positive user habits (i.e., carpooling). A key issue with facility-based systems' opt-in management method is the reliance on transponders tied to online, registered payment accounts. Most transponder charging systems require users to have regular internet access and a bank account, not to mention the upfront cost of acquiring a transponder can be almost CAD$100. While some systems have taken steps to provide increased payment options including pre-payment, license plate capture and billing, and transponder stickers in addition to portable hard case models, users often find that there is a significant financial disadvantage to not participating with a transponder account. In the case of Denver's 1-25 Central Express Lanes users paid up to 65% more if they used the License Plate Toll program rather than a pre-paid transponder.

Adequately adjusting fees to improve system fairness and equity is another area in which facility-based systems struggle. The ability to opt-out doesn't immediately make HOT lanes equitable, particularly since they overwhelmingly replace a free service (HOV lanes). Melbourne's EastLink tollway is notable for its implementation of a hardship policy designed to support users in managing their toll repayments while experiencing short-term financial hardship. Melbourne's hardship policy is most reminiscent of the discount and exemption policies common to area-based systems. Discounts and exemptions promote a sense of system fairness by reducing the financial burden on individuals who must participate (i.e., residents, users with disabilities) and provide clear and simple financial benefits for users who participate in positive transit activities such as riding public transit, carpooling, or using LEZ/ZEVs.

3.4.8 Political acceptability

Many local governments avoid pursuing congestion pricing systems as a policy to motivate behaviour change in the public due to a perception that they have low public acceptability. However, of the implemented systems studied the majority saw moderate to high public acceptability when reviewed during public referendums, pre- and post-implementation studies and in the media. Specifically, there is a sharp increase in public acceptability of congestion pricing systems post-implementation (see Figure 19) which speaks to the impact of user uncertainty on system success. Even systems that lacked quantitative data on public acceptability followed a similar qualitative trend users were skeptical of the system prior to implementation, but once they saw the results their perception grew more positive (Guse, 2019; Shewmake, 2018).

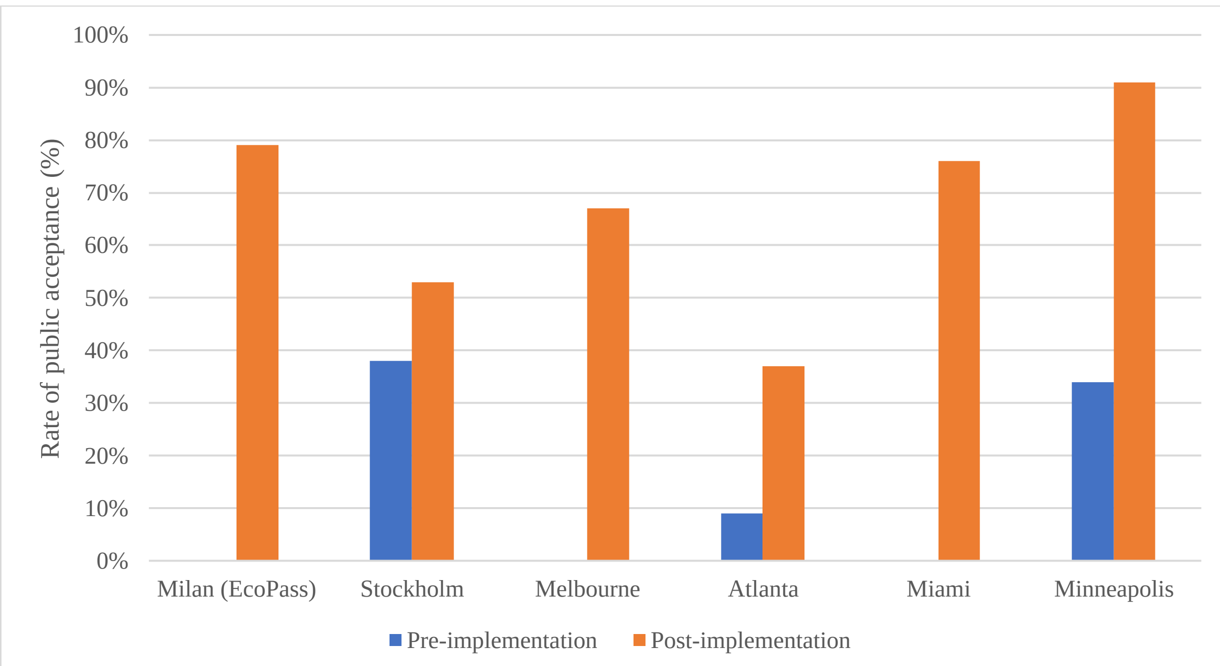

Figure 19: Public acceptability rates of congestion pricing systems pre- and post-implementation. Some systems lack pre-implementation data and therefore only display post-implementation rates.

Chapter 4: Discussion

The content analysis highlights several design considerations for implementing congestion pricing systems. First, the public is hesitant to embrace systems which disturb their status quo (Selmoune et al., 2020). There is no potential for emissions reductions if congestion pricing systems are unable to pass the proposal stage. Gu et al. (2018) and Selmoune et al. (2020) have described how overly complex systems lead to user uncertainty. Ensuring congestion pricing systems are simple enough for the public to understand is a key factor in ensuring proposals move forward into implementation (Gu et al., 2018). Area-based systems create a low barrier of access for users; system pricing is fixed or free to enter and designated entry points clearly delineate restricted and non-restricted travel zones. Fixed pricing is simple for users to understand and budget for – unlike dynamic congestion-based pricing where a user can't accurately predict the cost until they reach the facility. Policymakers should be mindful when utilizing time variable pricing which can quickly become overly complex, particularly when integrated with other pricing factors such as seasonality or trip type.

Second, protecting user privacy is an important step in ensuring congestion pricing proposals move forward to implementation (Gu et al., 2018; Selmoune et al., 2020). While data collection is of great political concern (Selmoune et al., 2020), the systems which infringe greatly on user privacy are often tied to more complex systems. Reducing points of interaction between the user and the congestion pricing facility can improve user privacy and reduce system complexity (i.e., restricted access points, facility charges upon entry). User registration was also found to have overlapping concerns of privacy and equity, making it particularly interesting as an area for future research. A historic complaint against congestion pricing systems is that they infringe upon an individual's "right to drive"(Lindsey & Santos, 2020, p. 3). However, reducing registration requirements shifts the focus of enforcement from enforcing the individual to enforcing the vehicle which supports perceived fairness – a necessary component for system acceptability as defined by Selmoune et al. (2020). Perceived fairness is achieved by remaining supportive of emission-reducing vehicle travel; this is particularly prevalent in systems where EURO vehicle emission standards dictate entry requirements (i.e., Milan – Area C, Paris, London LEZ).

Third, the finding that public acceptability increases significantly after system implementation aligns with existing research on the need for public education during the implementation process (Gu et al., 2018; Hysing & Isaksson, 2015; Selmoune et al., 2020). This past research identified four types of public engagement undertaken by cities: trial periods, public referendums and bylaw implementation, professional studies, and public consultation and surveys. While this study further confirms the importance of trial periods and referendums as part of the implementation process (Gu et al., 2018; Hensher, 2013; Selmoune et al., 2020), it also introduces professional road studies, public consultation, and pre-implementation surveys as potentially important parts of the public education process and a focus for future research. The narrative that congestion pricing is a publicly unpopular policy option fails to account for the significant shift in public acceptability that occurs after implementation. Trial periods have not been widely utilized by local governments seeking to implement congestion pricing systems; however, they are a uniquely effective tool for reducing public uncertainty in new congestion pricing systems (Gu et al., 2018). As seen in Stockholm, trial periods can provide a modest but impactful change in public perception of congestion pricing. Policymakers should consider how tools like trial periods can be used to increase pre-implementation rates of acceptability.

Fourth, the project findings support Ku et al.'s (2020) research on European LEZs. Specifically, area-based systems can achieve small, but consistent reductions in GHG and air quality emissions and should be considered as part of a suite of transportation demand management policies. Congestion pricing systems have the potential for greater emissions abatement by leveraging their revenue stream and emissions-based fee structures. Revenue can be reinvented into public and active transit projects to reduce overall vehicular use. While systems which use an emissions-based fee structure – whether no/low-cost or traditionally priced – can be used in tandem with ZEV transition policies to encourage the uptake of lower-emission vehicles. PM_{10} emission abatement was particularly successful with area-based systems. Lisbon stood out for its unusually high rate of abatement compared to the other evaluated systems. While emission abatement was not overwhelming among pricing systems, this study challenges Börjesson et al.'s (2021) assessment that equity impacts outweigh the abatement benefits – particularly among zonal systems which often do not charge users and limit travel data collection. Further research should investigate the impact of international disciplinary measures (i.e., EU fines for poor air quality) on emissions abatement policies, as the greatest abatement results were found in Lisbon, London, and Milan – all European cities with a history of air quality concerns. Local governments could also benefit from consistently collecting baseline GHG and air quality emissions data prior to implementation to increase the accuracy of emissions abatement calculations.

Fifth, revenue recycling into transit services and infrastructure is important for increasing public acceptability and user equity. These findings align with previous research on revenue recycling as a form of credible commitment to accessible transportation (Kidokoro, 2010; Manville & King, 2013). Area-based systems were found to have mostly structured revenue recycling schemes, while facility-based systems lacked a clear relationship between revenue recycling and user mode shift. More research into the factors which influence mode shift in facility-based systems is needed.

Sixth, facility-based systems are not necessarily a more equitable option than area-based systems. While users may opt not to engage with facility-based systems and still drive to their desired destination (unlike with area-based systems), the option to opt out of the system does not address how these changes impact users who previously accessed a free HOV lane. While facility-based systems are most likely to perform pre- and post-implementation surveys to assess public attitudes, mode shift and equity impacts (Goel & Burris, 2012; Guensler et al., 2020; Khoeini & Guensler, 2014), they have the fewest options in place to mitigate the cost to users and impact of more stringent HOV requirements for low-income users. However, zonal systems can restrict access at little to no cost to the user, tailor user exemptions (i.e., residents, vehicles for the disabled, agricultural vehicles), and even reduce negative user privacy impacts by implementing cordon-style access points.

Chapter 5: Conclusion

The study employed content analysis to examine the application of global congestion pricing systems and identify the key design features that are most desirable for achieving GHG and air emission reductions. The study identified 16 congestion pricing systems across 11 cities within the OECD which met the inclusion criteria. Each system was evaluated across implementation context, design characteristics, effectiveness, and political acceptability-- common criteria used in environmental and transportation multi-attribute trade-off policy analysis. The assessment employed quantitative and qualitative content analyses of academic literature, policy documents, and news articles. While congestion pricing is primarily considered a method of restricting vehicular traffic to an area to reduce congestion, excess vehicular traffic also creates negative externalities such as GHG and air quality emissions which negatively impact the climate and human health.

Overwhelmingly, area-based congestion pricing systems were found to provide local governments with a relatively revenue-positive tool for GHG and air quality emissions abatement. Simple systems that target vehicle emissions of key concern to a jurisdiction can lead to small but consistent emissions reductions over time, particularly in regions with pre-existing air quality concerns as seen in London, Lisbon, and Milan. Area-based systems also saw the fewest negative impacts on user equity as these systems built in charge exemptions for users most at risk of being financially disadvantaged by the system (i.e., residents). Discounts and exemptions were also used to reward positive behaviour by users (i.e., mode shift from single- to high-occupancy vehicles, changing to a more efficient vehicle). While facility-based systems also reward user behaviour with discounts, most systems fail to engage with their negative impact on low-income and existing HOV-commuters. Historically, congestion pricing systems have been considered difficult to implement due to low public acceptability. This study shows that the post-implementation acceptability of systems is consistently high. As a result, trial periods – which have been used infrequently in congestion system implementation – should be considered more frequently by policymakers looking to introduce congestion pricing systems as a policy tool. They provide an opportunity for the public to engage with the system prior to formal implementation, reduce user uncertainty, and increase public acceptability.

This study has several limitations which also provide opportunities for future research. First, older systems and systems outside of the OECD were excluded from the study – these include established congestion charging systems in Mexico City and Singapore. Small systems and systems in economically small cities were also excluded. As the global emphasis on tackling climate change continues to increase, there is significant room for future research on European zonal congestion pricing systems in both small and large cities. Second, the literature search excluded bridges in our facility-based systems, focusing exclusively on larger HOT lanes and expressway facilities. Bridge tolling could provide an avenue for future research focused on facility-based congestion pricing systems. Third, consistency in data collection was inhibited due to language barriers and a lack of standardized pre-implementation data at the local level. While ex-post econometric, equity, and emissions studies were useful for this research, they inhibit the types of analysis that can be performed and cannot fully replace source data. Fourth, the implications of overlapping climate policies on emissions reduction are not addressed in this research. Future studies should consider methods of allocating emissions reductions to climate policies in overlapping jurisdictions. Finally, data on public acceptability comes from a mixture of government, private research, and news sources. Acceptability is integral to congestion pricing system implementation; it would be beneficial to analyze more standardized data on public sentiment – both pre-and post-implementation – using consistent historical sources or conducting large international surveys to obtain stated preference data using one survey instrument.

Despite the aforementioned limitations, the study offers valuable policy insights for local governments that are seeking to reduce GHG and air quality emissions and congestion at the same time. First, while the public is hesitant to embrace new congestion pricing systems, reducing system design complexity can improve public sentiment. Second, simpler systems offer lower impacts on user privacy. Third, public acceptability of pricing systems consistently increases after implementation, utilizing activities such as trial periods can help increase public acceptability prior to a full system implementation. Fourth, overwhelmingly congestion pricing systems do not achieve large reductions in GHG emissions, instead supporting small but consistent year-over-year reductions. Fifth, revenue recycling can help improve system acceptability through credible commitment and improve equitable access to alternative transit methods. Finally, tailored exemptions to area-based charges often result in a fairer fee structure than facility-based systems which rely heavily on allowing the user to opt-out of the system. With thoughtful design and implementation – focused on simplicity, equity, and user engagement – congestion pricing systems can achieve broad acceptability and help local governments seeking effective climate action.

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Appendices

Appendix A: Evaluative criteria of cordon pricing systems

City	Design characteristics			Effectiveness				Public support
	User privacy impacts	Simplicity	Revenue use	Emissions abated	Modal shift	Net revenue	Equity impacts	
Milan, Italy (EcoPass)	Camera enforcement is limited to cordon perimeter	• Fixed pricing • Emission-based charging using EURO standard	Revenue recycling – public/active transit	Difference in concentrations after 1 year: • CO: 0.05% • O_3: 4.17% • PM_{25}: -1.21% After 90 days: • PM_{10}: -17.77% • SO_2: -3.90%	• 28% reduction in tolled vehicles after 2 years • Public transportation increased by 1300 runs and 7.3% daily passenger capacity in the first 11 months	• Appx. €0.65M (CAD$1.1M) annually	Limited research shows a negative impact on homeowners within the cordon zone	79% voter approval to continue system
Milan, Italy (Area C)	Camera enforcement is limited to cordon perimeter	• Fixed pricing • Limited charge types based on user type	Revenue recycling – public/active transit	Difference in concentrations after 1 year: • PM_{10}: -18% • NO_x: -10% • NH_3: -31% • CO_2: -22%	Average change in entering traffic compared to 2011 • Year 1: -31% (appx. 41,000 admissions/day) • Year 3: -29% (appx. 38,560 admissions/day) • Year 6: -35% (appx. 46849 admissions/day)	• Appx. €13.1M (CAD$20.8M) annually	N/A	(see Milan – EcoPass)
Stockholm, Sweden	Camera enforcement is limited to cordon perimeter	• Variable pricing • Requires users to be aware of peak time-of-day and seasonal pricing	Revenue recycling – public transit & road infrastructure	N/A	Avg change in traffic compared to 2005: • Year 1 (2007): -18.7% • Year 3: -18.2% • Year 6: -21.4%	• Appx. SEK 888.5M (CAD$140.8M) annually	Post-implementation user surveys identified limited gendered equity impacts and no income-specific impacts	• 53% voter approval to continue system • 15% increase in public perception during trial period

(Agenzia Mobilità Ambiente e Territorio, 2022; Agenzia Mobilita Ambiente Territorio (AMAT), n.d.; Croci, 2016; Franklin, 2012; Hysing & Isaksson, 2015; Lehe, 2019)

Appendix B: EURO vehicle emissions compliance standards

The aim of Euro emissions standards is to reduce the levels of harmful exhaust emissions to improve European air quality. Targeted emissions include (RAC Motoring Services, 2023):

- Nitrogen oxides (NOx);
- Carbon monoxide (CO);
- Hydrocarbons (HC); and
- Particulate matter (PM).

Vehicles sold up to a certain year should conform to the appropriate EURO emissions standard below[15]; however, those older than the dates below won’t have a EURO standard and may be banned from entering designated zones, towns, or cities at certain times (RAC Motoring Services, 2023).

Table 7: EURO vehicle emissions standards (RAC Motoring Services, 2023).

Vehicle registration date	**Emissions standard**
31 December 1992	EURO 1
1 January 1997	EURO 2
1 January 2001	EURO 3
1 January 2006	EURO 4
1 January 2011	EURO 5
1 September 2015	EURO 6

[15] There can be some variation between vehicles and a vehicles’ manufacturer can confirm the EURO standard (RAC Motoring Services, 2023).

Appendix C: Evaluative criteria of facility-based pricing systems

City	Design characteristics			Effectiveness				Public support
	User privacy impacts	Simplicity	Revenue use	Emissions abated	Modal shift	Net revenue	Equity impacts	
Melbourne, Australia	• Camera enforcement for length of facility • Transponders don't require registration for use	• Variable price based on distance traveled • Cost also modified by trip and vehicle type	N/A	Difference in concentrations after 1 year[16]: • $PM_{2.5}$: 89% • PM_{10}: 23% • NO_2: 8% • CO: -2%	N/A	N/A	• Hardship policy provides short-term financial support • Tag accounts cost users significantly less than alternative payment options	• 67% positive public opinion of toll use • Initial negative perception of tolls
Atlanta, USA	• Camera enforcement for length of facility • Transponders require registration for use	• Dynamic, congestion-based pricing prevents users from predicting cost prior to travel	N/A	Difference in concentrations after 1 year[17]: • HC: -3.7% • $PM_{2.5}$: -3.1% • NO_x: -5.7% • CO: -3.9% • CO_2: -1.9%	% change in fleet composition after 1 year: • Passenger vehicles: 16.3% • Light-duty vehicles: -12.5% • Heavy-duty vehicles: -65.3% • Buses: 13.3%	N/A	• Must have a tag account to access facility – requires bank account access	• Pre-implementation public opinion was very low • Post-implementation saw increased perception of commute conditions – not necessarily system itself

[16] Concentrations of PM2.5 and PM10 are compared against annual 24-hour maximum concentrations, while NO2 and CO are compared against annual 1-hour maximum concentrations. Assessment criteria were based on the State Environment Protection Policy (Air Quality Management) Schedule B intervention levels.

[17] Average change of mass emissions at peak a.m. and p.m. times across all lanes.

City	Design characteristics			Effectiveness				Public support
	User privacy impacts	Simplicity	Revenue use	Emissions abated	Modal shift	Net revenue	Equity impacts	
Denver, USA	• Camera enforcement for length of facility • Transponders do not require registration for use	Variable time-of-day pricing supports user cost planning, assuming a perfectly timed trip	N/A	N/A	Express lane implementation had limited impact on user mode shift. 54% of drivers travelled alone four or more days a week irrespective if they were using an express lane or not	Appx USD$3M (CAD$5.5M) annually	• Tag accounts are more cost effective than alternative payment options • New park-and-ride lots implemented	N/A
Houston, USA	• Manual enforcement for length of facility • Transponders require registration for use	• Variable time-of-day pricing allows users cost planning, assuming a perfectly timed trip • Reversible lanes create added complexity for driver navigation	N/A	N/A	% change in monthly ridership (2016): Local buses: • 2017: -1% • 2018: 1% • 2019: 4% • 2020: -42% • 2021: -31% Park & Ride: • 2017: -7% • 2018: -7% • 2019: 4% • 2020: -84% • 2021: -71%	Appx USD$0.015M (CAD$0.032M) annually	• Must have tag account to access facility • Express bus and park-and-ride facilities integrated with system	N/A
Miami, USA	• Camera enforcement for length of facility • Transponders require registration for use	• Dynamic, congestion-based pricing prevents users from predicting cost prior to travel	N/A	N/A	• 57% increase in average bus ridership between 2008 and 2010. • 72% of new riders were influenced by the 95 Expressway implementation.	N/A	• Multiple tag options and can be purchased from physical retail outlets • Additional non-financial tools available support mode shift to	Of Phase 1 post-implementation survey respondents: • 76% said service was faster and more reliable • 56% in favor of expansion

City	Design characteristics			Effectiveness				Public support
	User privacy impacts	Simplicity	Revenue use	Emissions abated	Modal shift	Net revenue	Equity impacts	
Minneapolis, USA (I-394)	• Manual enforcement for length of facility • Transponders require registration for use	• Dynamic, congestion-based pricing prevents users from predicting cost prior to travel • Reversible lanes create added complexity for driver navigation	Revenue recycling – road infrastructure and transit	N/A	N/A	-USD$0.2 million annually (-CAD$0.3 million)	N/A	• Pre-implementation public opinion was mixed, with carpool and bus users opposed and SOV users strongly in favour • Post-implementation surveys showed 91% satisfaction with the MnPass system
Minneapolis, USA (I-35W)	• Manual enforcement for length of facility • Transponders require registration for use	• Dynamic, congestion-based pricing prevents users from predicting cost prior to travel.	Revenue recycling – road infrastructure and transit	N/A	• 13% increase in average bus ridership between 2009 and 2011. • 23% of new bus riders influenced by MnPass lane implementation.	N/A	N/A	• Pre-implementation public opinion was mixed, with carpool and bus users opposed and SOV users strongly in favor. • Post-implementation surveys showed 91% satisfaction with the MnPass system

(Goel & Burris, 2012; Guensler et al., 2020; METRO, 2017, 2019, 2021; Minnesota Dept of Transportation, n.d.-d; Pessaro et al., 2013; Transfield Services Pty. Ltd., 2009, 2010; Xu et al., 2017)

Appendix D: Evaluative criteria of zonal pricing systems

City	Design characteristics			Effectiveness				Public support
	User privacy impacts	Simplicity	Revenue use	Emissions abated	Modal shift	Net revenue	Equity impacts	
Paris, France	• Manual enforcement • No camera or GPS integration • One-time purchase, no registration required	• Crit'Air directly correlates to EURO standards • One-time purchase • Only one zone	N/A	Average change in annual emission concentrations between 2010 to 2016: • NO_x: -1.9% • NO_2: -2.9% • PM_{10}: -4.3% • $PM_{2.5}$: -5.2%	N/A	N/A – system has a one-time user fee	• Low barrier for entry for users who already meet the standards • Multiple financial programs have been implemented to support mode shift and reduce the potential burden of the LEZ • Infrastructure programs have also been implemented to make new modes of travel more accessible	N/A
Milan, Italy (Area B)	• Camera enforcement • No registration required	• Uses EURO standards • No entry fees • Zones don't overlap	N/A	Change in annual emission concentrations: 2019 • PM_{10}: -14% • NO_x: -4 to -5% 2020 • PM_{10}: -24% • NO_x: -4 to -5% 2021 • PM_{10}: -21%	N/A	N/A – system is free for users to access	• Low barrier for entry for users who already meet the standards • Significant investments have been made in public transit alternatives to support mode shift	N/A

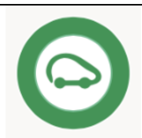
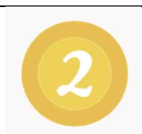
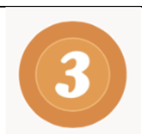
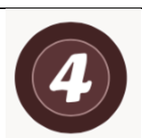
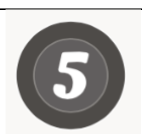
City	Design characteristics			Effectiveness				Public support
	User privacy impacts	Simplicity	Revenue use	Emissions abated	Modal shift	Net revenue	Equity impacts	
				• NO_x: -4 to -5%				
Lisbon, Portugal	• Camera and manual enforcement • Registration required	• Uses EURO standards • No entry fees • Zones do not overlap	N/A	Average change in annual emission concentrations between 2009 and 2016: Zone 1 • PM_{10}: -29% • NO_2: -12% Zone 2, • PM_{10}: -23% • NO_2: -22%	N/A	N/A – system is free for users to access	• Low barrier for entry for users who already meet the standards • Minimal financial programming available to support mode shift for users • No investments in existing infrastructure to support mode shift	N/A
London, UK (LCC)	• Camera enforcement • Registration required for some vehicles	• Uses EURO standards • Overlapping zones increase fee structure complexity • One payment portal for all three zones	Revenue recycling – public transit operations	Overall change in emission concentrations between 2003 and 2005: • PM_{10}: -15% • NOx: -13% • CO_2: -16%	• Between 2002 and 2003 half of new bus ridership attributed to LCC.	• Appx. £92.5M (CAD$275.2M) annually • The system has £143M (CAD$425.4M) in diplomatic debt (LCC fee is not exempt for diplomats)	Significant discount, rebate, and exemption options to reduce financial burden on equity groups (i.e., residents, disabled persons)	Low public support for LCC expansion but both LEZ and ULEZ have seen high rates of compliance
London, UK (LEZ & ULEZ)	• Camera enforcement • Registration required for some vehicles	• Uses EURO standards • Overlapping zones increase fee structure complexity • One payment	Revenue recycling – public transit operations	Overall change in emission concentrations between 2008 and 2013 (LEZ): • PM_{10}: -20% Average quarterly change in	• LEZ users doubled compliance to 96% over 4 years • ULEZ users 94% compliant	System is free for users who meet the eligibility criteria with fixed fees for all other users	• Low barrier for entry for users who already meet the standards • Minimal financial programming available to support mode shift for users	See LCC

City	Design characteristics			Effectiveness				Public support
	User privacy impacts	**Simplicity**	**Revenue use**	**Emissions abated**	**Modal shift**	**Net revenue**	**Equity impacts**	
		portal for all three zones		emission concentrations between 2019 and 2022 (ULEZ)[18]: • $PM_{2.5}$: -43% • NO_2: -29%	within 6 months		• Some non-financial programming to support mode shift for users • Significant discount, rebate, and exemption options to reduce financial burden on equity groups (i.e., residents, disabled persons)	

(Croci, 2016; Font et al., 2019; Greater London Authority, 2021; Mayor of London, 2022; Municipality of Milan, 2022a; F. M. Santos et al., 2019; TfL, 2022a)

[18] These are the average changes for the inner roadside collection points, the Mayor of London (2022) report also provides data for Background Central, Background Inner, Background Outer, and Roadside Outer collection points.

Appendix E: Crit'Air classification system for Paris' Low Emission Zone

Crit'Air Sticker	Crit'Air Categories	Vehicle Type
	Green – Crit'Air E	Zero emissions vehicles • All 100% electric and hydrogen vehicles.
	Purple – Crit'Air 1	Gas and rechargeable hybrid vehicles • All gas vehicles and all plug-in hybrid vehicles • Euro 5, 6 petrol vehicles • Euro 6 petrol HGVs • Euro 6 Biodiesel HGVs • Euro 4 2-wheel vehicles (i.e., motorcycles)
	Yellow – Crit'Air 2	• Euro 4 petrol vehicles, Euro 5 petrol HGVs • Euro 5, 6 diesel vehicles, Euro 6 diesel HGVs • Euro 3 2-wheel vehicles (i.e., motorcycles)
	Orange – Crit'Air 3	• Euro 2, 3 petrol vehicles, Euro 3, 4 petrol HGVs • Euro 4 diesel vehicles, Euro 5 diesel HGVs • Euro 5 Biodiesel HGVs • Euro 2 2-wheel vehicles (i.e., motorcycles)
	Burgundy – Crit'Air 4	• Euro 3 diesel vehicles, Euro 4 diesel HGVs • Euro 4 Biodiesel HGVs • 2-wheel vehicles without standard from June 2000 to June 2004
	Dark Grey – Crit'Air 5	• Euro 2 diesel vehicles, Euro 3 diesel HGVs • Euro 3 Biodiesel HGVs
N/A	Unclassified	• 2-wheel vehicles without standard until May 31, 2000 • Euro 1 and before petrol vehicles, Euro 1, 2 petrol HGVs • Euro 1 and before diesel vehicles, Euro 1, 2 and before diesel HGVs • Euro 1, 2 and before biodiesel HGVs

(Ministry of Ecological Transition & Territorial Cohesion, n.d.-b, n.d.-a; RAC Motoring Services, 2022).

Appendix F: Vehicles eligible for discount or exemption from the London ULEZ

- Community transport minibuses can receive a temporary 100% discount until October 26, 2025 – at which point all minibuses will be expected to meet ULEZ emission standards;
- Showman's vehicles can receive a 100% discount if registered with the TfL;
- NHS patients too ill to travel on public transit can receive a reimbursement for travel to their treating hospital;
- Vehicles for disabled people can receive a temporary exemption through one of three application streams until October 25, 2027;
- Wheelchair-accessible private hire vehicles (PHVs) can receive a temporary exemption until October 25, 2027;
- London-licensed taxis are exempt, with 12- and 15-year age-limits on existing fleet vehicles and a requirement that newly licensed vehicles be zero emission capable;
- Historic vehicles are exempt (foreign vehicles need to register with the TfL to receive their exemption); and
- Certain other specialty vehicles including agricultural vehicles, military vehicles, non-roadgoing vehicles (i.e., excavators), and certain mobile cranes are exempt.

(TfL, n.d.-c)