ENVIRONMENTAL SUSTAINABILITY OF LIGHT RAIL TRANSIT IN URBAN AREAS

by

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ABSTRACT

HAZEL MARIE ACHACOSO SARMIENTO. Environmental sustainability of light rail transit in urban areas. (Under the direction of DR. EDWIN W. HAUSER)

Light rail transit is considered as an environmentally sustainable transit option based on perceptions of its possible benefits on minimizing air pollution, energy consumption and greenhouse gas emissions. This study seeks to determine how light rail presence affects environmental sustainability in urban areas. For urban areas with existing light rail systems, this study also seeks to determine how light rail, urban area and public transit characteristics affect environmental sustainability. Environmental sustainability indicators were selected based on the environmental sustainability goals of minimizing air pollution, energy resource use and greenhouse gas emissions. Environmental sustainability goals were measured as air quality index, energy intensity, energy consumption per capita, carbon dioxide emissions intensity, and carbon dioxide emissions per capita as outcome variables. Using urban area and public transit data from 2000 to 2011, the impacts of light rail presence and other forms of rail transit on selected environmental sustainability indicators were estimated through a series of multiple regressions with light rail, urban area and public transit characteristics. Findings indicate that light rail presence affects environmental sustainability in varying degrees for each of the outcome variables. Light rail presence increases the predicted values for air quality index, but does not significantly affect energy intensity, energy per capita, CO_2 intensity and CO_2 per capita. Possible determinants of the selected environmental sustainability indicators include light rail ridership, light rail directional route miles, light rail operating expenses, and light rail passenger miles traveled. Housing density and employment density also significantly affect environmental sustainability indicators. Public transit ridership, directional route miles, and the number of vehicles operating at maximum service also affect environmental sustainability. The results of the study imply that light rail presence is not sufficient to influence environmental sustainability. Other factors are required, such as light rail transit ridership, which also influences how light rail transit affects the environmental sustainability in urban areas.

Keywords: Light rail transit, environmental sustainability, sustainable transportation

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LIST OF ABBREVIATIONS

AQI	air quality index
Btu	British thermal unit
BCA	benefit-cost analysis
CEA	cost-effectiveness analysis
CO2	carbon dioxide
CRT	commuter rail transit
CST	Center for Sustainable Transportation in Canada
DO	Direct operations
DOT	Department of Transportation
ECMT	European Conference of Ministers of Transport
EIA	environmental impact assessments
EPA	Environmental Protection Agency
ESCOT	Economic Assessment of Sustainability Policies of Transport
EST	environmentally sustainable transport
FTA	Federal Transit Administration
HRT	heavy rail transit
IEA	International Energy Agency
LCCA	life cycle costs analysis
LRT	light rail transit
MCA	multi-criteria approaches
NAICS	North American Industry Classification System
NTD	National Transit Database

OECD	Organisation for Economic Co-Operation and Development
OLS	ordinary least squares
POV	privately owned vehicle
PPP	policies, plans and programs
PT	purchase transportation
ROW	right-of-way
RQ1	research question #1
RQ2	research question #2
SEA	strategic environmental assessments
SPARTACUS	Systems for Planning and Research in Towns and Cities for Urban Sustainability
UNCED	United Nations Conference on Environment and Development
UPT	unlinked passenger miles
UZA	urbanized area
VOMS	vehicles operating at maximum service
WCED	World Commission on Environment and Development

CHAPTER 1: INTRODUCTION

Among all forms of passenger rail, the light rail transit is perceived to be a sustainable public transit option and an alternative to automobile use, bus systems, commuter and heavy rail, and other special transportation services. Rail, in general, is a fuel efficient transport mode especially in comparison to cars and trucks, because of its capability to transport more passengers or goods (in the case of freight rail systems) to destinations, which results in less fuel use per miles traveled and less carbon dioxide emissions (Fietelson, 1994). Passenger rail, in the form of light rail, heavy rail and commuter rail, is designed to serve local and regional transportation networks in high frequency and higher ridership levels (Arndt, Morgan, Overman, Clower, Weinstein, & Seman, 2009). Light rail and heavy rail are both electric rail services and serve local networks with typical distances of around one mile in between stops. They differ in the volume of passenger capacities, loading platforms and rights-of-way. However, compared to commuter rail, light rail and heavy rail services are concentrated on the central business area. Commuter rail serve local short distance travel between central city and adjacent suburbs, integrating passengers in various parts of urban areas that use public transit – whether bus, rail or special transportation services. Table 1.1 provides a comparison of the basic characteristics of light, heavy and commuter rail as defined in the National Transit Database (Federal Transit Administration (FTA), 2013).

Among all forms of passenger rail, the light rail transit is perceived to be a sustainable public transit option and an alternative to automobile use, bus systems, commuter and heavy rail, and other special transportation services. This perception is based on the notion that light rail characteristics adhere to sustainable transportation principles and that light rail has the ability to address economic, social and environmental goals that are geared towards ensuring that resources are available for future generations. Supported by various studies on rail transit benefits (Newman & Kenworthy, 1999; Schiller, Bruun, & Kenworthy, 2010; Litman, 2012a), light rail has the potential to solve urban congestion and pollution problems, reduce petroleum independence, and promote efficient urban development patterns. Light rail characteristics concur with the sustainable development and sustainable transportation agenda, which calls for development that is transit-oriented, with transit options that are competitive with automobiles, with transportation options that reduce energy use, emissions, noise and other externalities, and with development that encourages efficient use of urban space (Newman & Kenworthy, 1999). Light rail transit has a positive influence on increasing transit ridership, reducing traffic congestion, and other economic, social and environmental benefits, including reducing greenhouse gas emissions, and less dependence on automobiles especially in urban sprawl areas (Litman, 2012a).

Light rail, as defined by the Light Rail Transit Subcommittee of the Transportation Research Board, is “a metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, on aerial structures, in subways, or occasionally, in streets, and to board and discharge passengers at track or car floor level” (European Conference of Ministers of Transport (ECMT), 1994). Compared to commuter rail and heavy rail, which has capacity for heavy volume traffic and a larger travel distance from center city to adjacent suburbs, light rail caters to lighter volume of passenger traffic (FTA, 2013).

Table 1.1: Characteristics of light rail, heavy rail and commuter rail

Particulars	Light Rail	Heavy Rail	Commuter Rail
Fuel Type	Electric Propulsion	Electric Propulsion	Diesel or Electric Propulsion
Traffic Volume Capacity	Light volume	Heavy volume	Heavy volume
Types of Rail Cars	Passenger rail cars operating singly (or in short, usually two car, trains)	High speed and rapid acceleration passenger rail cars operating singly or in multiple cars	Either locomotive hauled or self-propelled railroad passenger cars
Type of Right of Way	Fixed rails in shared or exclusive right-of-way (ROW)	Fixed rails on separate rights-of-way (ROW) from which all other vehicular and foot traffic are excluded	Exclusive fixed rail, may be shared with freight rail
Network	Local	Local	Local or Regional
Platform Loading	Low or high	High	High
Distance Stops	0.25 mile to 1 mile	1 mile	Several miles

Source: Arndt, et al., 2009; National Transit Database Glossary (Internet: http://www.ntdprogram.gov/ntdprogram/Glossary.htm);

The National Transit Database reports that there are twenty nine (29) transit agencies that provided light rail services to around 434 million riders in 2011 (Table 1.2). These agencies provide light rail services to twenty-seven (27) urban areas either through direct operations (DO) or purchase transportation (PT) services (Federal Transit Administration (FTA), 2012a). Directly operated (DO) transportation is service provided by the transit agency, using their employees to supply the necessary labor to operate the revenue vehicles. Purchased transportation (PT) on the other hand is provided to a public transit agency or governmental unit from a private transportation provider based on a written contract. For this service, the provider is obligated in advance to operate public transportation services for a specific monetary consideration using its own employees to operate revenue vehicles (FTA, 2013). Total service routes for all urban areas with light rail cover 807 miles, with light rail from Dallas (Texas), Los Angeles metro area (California), New York metro area (New York) and San Diego (California) having the longest routes, and Kenosha (Wisconsin) and Little Rock (Arkansas) with the shortest routes (Table 1-2). In terms of service area population, the New York-Newark, NY-NJ-CT urban area has the largest service area population, while Kenosha, WI has the lowest service area population.

Since the beginning of the light rail movement in North America in the 1960s, light rail has provided an alternative transport option to bus transit, changed people’s travel behaviors and improved urban transportation conditions (Thompson, 2003). Urban development patterns in the 1960s and the 1970s required massive capital improvement projects for mass transit, like heavy rail, commuter rail and bus systems, to catch up with urban population growth travel volumes and changing growth patterns in cities. Massive transportation investments were made, including the construction of the interstate highway system. In addition, the wave of suburbanization in American cities contributed to rapid population growth. By the 1980s, the cost of massive capital improvement projects outpaced available funds for construction of heavy rail and other transportation projects. Light rail became an adequate and practical alternative to heavy rail. With funding available through the Federal Transit Administration, and with project conditions that indicate need, based on urban densities, travel volumes and growth patterns, light rail construction increased during the period. Light rail, when available in urban areas, became the most diversified and competitive transportation mode compared to the use of automobile with respect to passenger appeal, speed and positive environmental impacts (Vuchic, 1999; Greenberg, 2005).

Background on Sustainability and Sustainable Transportation

By the 1990s, the idea of sustainability emerged from discussions organized by the United Nations World Commission on Environment and Development (WCED) in 1987, the United Nations Conference on Environment and Development (UNCED) in 1992, and in succeeding initiatives by the Organisation for Economic Co-Operation and Development (OECD) in the late 1990s. The WCED, more popularly known as the Brundtland Commission, defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). The concept of sustainability is initially based on concerns on providing for the needs of future generations and then evolved into a discussion on developing policy frameworks that address various sectors of society and covering economic, social and environmental issues. These three issues became the “triple bottom line” of sustainability – economic, social and environmental sustainability. This approach made policy discussions and sustainability initiatives more manageable than the dealing with the overarching intergenerational idea of sustainable development.

Table 1.2: Profile of transit agencies that operate light rail in the United States

Transit Agency	Urbanized Area Served	Length of Service Route (in miles)
Maryland Transit Administration	Baltimore, MD	28.8
Massachusetts Bay Transportation Authority	Boston, MA-NH-RI	25.5
Niagara Frontier Transportation Authority	Buffalo, NY	6.2
Charlotte Area Transit System	Charlotte, NC-SC	9.3
The Greater Cleveland Regional Transit Authority	Cleveland, OH	15.2
Dallas Area Rapid Transit	Dallas-Fort Worth-Arlington, TX	71.8
Denver Regional Transportation District	Denver-Aurora, CO	35.0
Metropolitan Transit Authority of Harris County, Texas	Houston, TX	7.4
Kenosha Transit	Kenosha, WI-IL	1.0
Central Arkansas Transit Authority	Little Rock, AR	1.9
Los Angeles County Metropolitan Transportation Authority	Los Angeles-Long Beach-Anaheim, CA	60.6
Memphis Area Transit Authority	Memphis, TN-MS-AR	5.0
Metro Transit	Minneapolis-St. Paul, MN-WI	12.4
New Orleans Regional Transit Authority	New Orleans, LA	12.7
New Jersey Transit Corporation	New York-Newark, NY-NJ-CT	58.1
Southeastern Pennsylvania Transportation Authority	Philadelphia, PA-NJ-DE-MD	41.2
Valley Metro Rail, Inc.	Phoenix-Mesa, AZ	19.6
Port Authority of Allegheny County	Pittsburgh, PA	23.7
Tri-County Metropolitan Transportation District of Oregon	Portland, OR-WA	52.2
Sacramento Regional Transit District	Sacramento, CA	36.9
Utah Transit Authority	Salt Lake City-West Valley City, UT	35.4
San Diego Metropolitan Transit System	San Diego, CA	54.0
North County Transit District	San Diego, CA	44.0
San Francisco Municipal Railway	San Francisco-Oakland, CA	41.6
Santa Clara Valley Transportation Authority	San Jose, CA	40.5
King County Department of Transportation - Metro Transit Division	Seattle, WA	1.5
Central Puget Sound Regional Transit Authority	Seattle, WA	17.5
Bi-State Development Agency	St. Louis, MO-IL	45.6
Hillsborough Area Regional Transit Authority	Tampa-St. Petersburg, FL	2.4

Source: National Transit Database (Federal Transit Administration, 2010-2011

Table 1.2: (continued)

Notes:

1. Light rail services are either directly operated (DO) or purchased transportation (PT). Directly Operated (DO) Transportation is service provided directly by a transit agency, using their employees to supply the necessary labor to operate the revenue vehicles. Purchased transportation (PT) is service provided to a public transit agency or governmental unit from a public or private transportation provider based on a written contract. The provider is obligated in advance to operate public transportation services for a public transit agency or governmental unit for a specific monetary consideration, using its own employees to operate revenue vehicles. (National Transit Database Glossary, FTA, 2012).
2. Ridership data is data from annual unlinked passenger trips from the National Transit Database (FTA, 2012). Ridership for Kenosha, Memphis, New Orleans, and Tampa are based on 2010 data. Data for 2011 is not available at the time data is collected.
3. Length of service route is from data from directional route miles from the National Transit Database (FTA, 2012). Directional route mile is the mileage in each direction over which public transportation vehicles travel while in revenue service. One direction of the public transportation vehicles travel while in revenue service. One direction of the directional route miles is the length of service route.

In the UNCED conference held in Rio de Janeiro (Brazil) in 1992, national governments endorsed Agenda 21, which states that “various sectors of human activity should develop in a sustainable manner”. One of the key sectors that were identified is transportation. The transportation sector became important because of concerns on how unsustainable the existing transportation systems are due to growth in transport activity, use of fossil fuels, air pollution, other environmental issues, and costs of motorized transport. The growth of transport activity over the years outweighed improvements in fuel efficiency and the control of emissions (Black W. R., 1996; Organisation for Economic Co-Operation and Development (OECD), 1997). These concerns became the driving force for including transportation in the sustainability agenda. Sustainable transportation, hence, became the expression of sustainable development in the transport sector. With consideration to the “triple bottom line of sustainability”, transportation options, such as cars, freight trucks, and public transit options, like bus and passenger rail, are usually analyzed and assessed based on their respective impacts on society, the economy and the environment.

Perceptions on the sustainability of light rail

Light rail concurs with the broad sustainability agenda for the following reasons (Newman & Kenworthy, 1999): its competitiveness with the use of automobiles for private transportation, its compatibility with the use of bicycles as an alternative mode of transportation, and its attractiveness to pedestrian and transit-oriented development that promotes appeal and livability in a local area. Because light rail is operated on electricity, which is a renewable source of energy, light rail is considered a faster and quieter mode of transport that has less local emissions compared to other forms of transit. In addition, light rail is flexible, can operate on existing transportation infrastructure and is adaptable in terms of passenger carrying capacity. Compared to construction costs and overall transit investment, light rail is a less expensive option than heavy rail or highway construction (Newman & Kenworthy, 1999). Other positive attributes of the light rail system also include functionality, quality, safety and reliability (Cervero, 1984; Newman & Kenworthy, 1999; Vuchic, 1999). Attributes of the light rail also satisfy criteria for an environmentally conscious public transportation, which considers transit facilities that are designed to influence sustainable development patterns, and emphasizes long-term environmental sustainability that reflects environmentally sound practices (Meyer, 2008). Light rail is considered as sustainable because of the system's potential to solve urban congestion and pollution problems, reduce petroleum independence and promote efficient development patterns. The permanence of rail transit lines and stations help generate the creation of attractive human environments, residential developments and business opportunities (Schiller, Bruun, & Kenworthy, 2010).

Despite the adoption, operation and competitiveness of light rail with other forms of transit, a number of critics have argued that the high initial costs to build the infrastructure, low ridership, the lack of return on investments and the opportunity cost for investing in other transportation services (like bus and other special transportation services, make light rail unsustainable. Case studies on selected operational light rail systems indicate that light rail may be less efficient, has higher opportunity costs and lower patronage levels (Gomez-Ibanez, 1985; Fielding, 1995). The opportunity cost for building other transit options, such as bus services, along with the value for money service capacity, affordability, flexibility and network coverage of light rail were also questioned (Semmens, 2006; Hensher, 2007). Critics also argue that light rail, in general, is outdated, has less ridership, is less cost effective, ineffective in terms of reducing congestion and emissions, inefficient, more expensive than bus operations, and does not benefit the poor (as presented in Litman, 2012b). This dissertation hopes to provide insights on the environmental impacts of light rail and how light rail affects environmental sustainability.

Rail transit experts, advocates and critics have differing views on the benefits of light rail as a sustainable transit option for urban areas. These opposing views, however, indicate room for additional discussions on the advantages and disadvantages of having a light rail service in the urban area. These discussions from various points of views lead to understanding and new knowledge on the many aspects of sustainability and sustainable transportation. Analysis on the different aspects of sustainability enriches the discussion and improves the literature on assessing sustainable transportation. Since the sustainable transportation concept emerged from concerns over the environment, a study focusing on light rail, being a sustainable transit option (as described), and how it specifically affects environmental sustainability can enhance and contribute to existing comprehensive assessment in the literature of light rail systems as a sustainable transit option in all sustainability aspects.

Statement of the problem

While there are comprehensive reviews of rail transit benefits in the literature (Litman, 2012a), empirical studies that have been conducted do not directly addresses light rail and its environmental sustainability benefits. Granting that sustainability and sustainable transportation are broad areas for discussion, a targeted and a more specific approach is needed to address the common perception and arguments for and against the environmental benefits of light rail in the urban area. Since the concept of sustainable transportation emerged from environmental concerns brought by transport activities, focus on the environmental aspect of sustainability is important. Key questions that need to be answered in addressing common perception on the sustainability of light rail include the following: Does light rail presence in urban areas contribute to environmental sustainability? Do other forms of passenger rail contribute to environmental sustainability? What is environmental sustainability and how is it measured? Aside from light rail presence, what other factors affect environmental sustainability indicators? A study on the impact of light rail presence in the urban areas can address these questions. In addition, identifying factors that affect environmental sustainability goals and indicators can provide us with additional understanding on the influence of light rail. Consequently, an empirical analysis can also provide insights on the plausibility of the differing perceptions on the environmental benefits of light rail.

This study hopes to address these issues and provide useful recommendations for sustainable transportation planning and policy.

Research Goals and Strategy

The primary goal of this research study is to provide an understanding of the influence of light rail presence on selected environmental sustainability indicators. The research questions for this study are expressed as follows:

1. How does light rail presence affect environmental sustainability indicators in urban areas?
2. For urban areas that have light rail systems, how do light rail, public transit, and urban area characteristics affect environmental sustainability indicators?

To determine how light rail contributes to environmental sustainability, environmental sustainability goals must be first identified, and matched with many possible factors that can explain these goals. While the precise definition for environmental sustainability is evolving with the introduction of many theoretical frameworks and metrics (Shane & Graedel, 2000; Joumard, 2011; Joumard, Gudmundsson, & Folkeson, 2011), the goals of environmental sustainability (Hall, 2006) can be summarized as follows:

- minimizing health and environmental damage;
- maintaining high environmental quality and human health standards;
- minimizing the production of noise;
- minimizing the use of land for transportation infrastructure;
- limiting the emissions and waste to levels within the planet’s absorptive capacity;

- ensuring that renewable resources are managed and used in ways that do not diminish the capacity of ecological systems to continue providing these resources;
- ensuring that non-renewable resources are used at or below the rate of development of renewable substitutes;
- ensuring that energy used is powered by renewable energy sources; and
- increasing recycling.

These goals address the negative environmental externalities associated with transportation: air pollution, consumption of land/urban sprawl, depletion of the ozone layer, disruption of ecosystems and habitats, climate change, light, noise, vibration, and water pollution, release of toxic and hazardous substances, solid waste, and depletion of non-renewable resources and energy supplies (Black W. R., 1996; Black & Sato, 2007; Hall, 2006; Environmental Protection Agency, 1996; Fietelson, 1994). While the goals are broad and measurement can be complex with many different variables to represent environmental issues (Etsy, Levy, Srebotnjak, & De Sherbinin, 2005), the environmental sustainability goals covered in this study are focused on minimizing pollution, minimizing energy resource use, and minimizing greenhouse gas emissions. These goals address the primary concerns that make existing transportation systems unsustainable. Indicators that represent these goals that are currently available and applicable to urban areas in the United States include air quality index (for minimizing air pollution), energy intensity and energy consumption per capita (for minimizing energy consumption), and carbon dioxide (CO2) emissions intensity and CO2 emissions per capita (for minimizing greenhouse gas emissions).

Possible determinants of environmental sustainability may include light rail, public transit and urban area characteristics. Urban area characteristics include metropolitan densities – population density, housing or residential density, and employment establishment density – which describe urban form. Urban form is the characterization of the built environment based on its constituent attributes and its mutual relations (Van Diepen & Voogd, 2001). A measure of mobility of people in the urban area, such as annual passenger miles traveled, can also affect environmental sustainability (Van Diepen & Voogd, 2001; Black, Paez, & Suthanaya, 2002). Light rail characteristics that can also affect environmental sustainability which include ridership (the number of passengers who board public transportation vehicles), the length of transit service routes for each direction, transit operating expenses, and the number of vehicles operated at maximum service (FTA, 2012a). Energy consumed by the light rail service and the level of carbon dioxide emissions from electricity used for light rail may also affect environmental sustainability. Aside from the presence of light rail, the presence of other forms of transit such as commuter rail and heavy rail are also included as determining factors for comparison.

The impacts of the relationship among these variables, with corresponding measurement indicators at the urban area level, can be estimated through a series of regression models, statistical analysis and impact analysis for changes in significant variables. This research strategy will provide an insight on how light rail presence contributes to the environmental sustainability in urban areas. The two research questions articulate the analytical framework for developing a model for assessment of environmental sustainability indicators in urban areas. The results of the analysis are expected to test and validate the following hypothesis:

1. Light rail presence in urban areas has a significant influence on minimizing air pollution, energy use and greenhouse gas emissions.
2. Light rail characteristics affect environmental sustainability goals.
3. Public transit characteristics affect environmental sustainability goals.
4. Urban densities affect environmental sustainability goals.

Under the sustainable transportation agenda, the results of this study demonstrate the relationship between light rail presence and selected environmental sustainability indicators. The results provide insights on identifying appropriate measures to represent environmental sustainability goals. While the objective of the analysis does not directly try to predict selected environmental sustainability indicators based on all the identified factors, the results of the study may validate this method and approach for sustainability assessment.

Theory Base for Research

The theoretical basis for this study is rooted on sustainable development and sustainable transportation. Sustainability has evolved from concerns on the impact of human activities on the environment to a more focused, issue-based discussion on the economic, social and environmental dimensions of sustainable development. The sustainability science covers an interdisciplinary approach to understanding the global, social and human systems that are crucial to the coexistence of human beings and the environment (Komiyama & Kazuhiko, 2006). Since the WCED defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987), this concept became a global mission. With the adoption of Agenda 21, sectoral focus is highlighted in all sustainability initiatives. Sustainable transportation became an expression of sustainable development in the transportation sector (OECD, 1997).

Sustainable transportation became part of the transportation policy agenda because of concerns on the unsustainability of existing transportation systems brought by the growth in transport activity, dependence on finite fossil fuel sources, air pollution from transport, other environmental issues concerning transportation and costs associated with motorized transportation (Black, 1996; OECD, 1997), energy resource consumption and institutional failures (Greene & Wegener, 1997). Intergenerational equity and the continuance of transportation for future generations also raises an issue affecting sustainability in transportation (Richardson, Toward a Policy on a Sustainability Transportation System, 1999). Succeeding studies further expanded the list of factors that make transportation systems unsustainable: fuel depletion, local atmospheric effects of motor vehicle emissions, lack of access, congestion, environmental degradation, vehicle crashes, personal injuries and fatalities (Richardson, 2005; Black & Sato, 2007). Understanding the factors that make transportation systems unsustainable led to many formulations of the definitions of sustainable transportation. A set of sustainable transportation principles was presented and endorsed in the Vancouver Conference organized by the OECD in 1996, which covered principles of access, decision-making, urban planning, environmental protection, and economic viability. Table 1-3 presents a summary of these principles (OECD, 1997).

Table 1.3: The Vancouver Conference principles of sustainable transportation

Principles	Description
Access	Improve access to people, goods, and services, but reduce demand for physical movement of people and things.
Decision-making	Make transportation decisions in an open and inclusive manner that considers all impacts and reasonable options.
Urban planning	Limit sprawl, ensure local mixes of land uses, fortify public transport, facilitate walking and bicycling, protect ecosystems, heritage, and recreational facilities, and rationalize goods movement.
Environmental protection	Minimize emissions and reduce waste from transport activity, reduce noise and use of non-renewable resources, particularly fossil fuels, and ensure adequate capacity to respond to spills and other accidents.
Economic viability	Internalize all external costs of transport including subsidies but respect equity concerns, promote appropriate research and development, consider the economic benefits including increased employment that might result from restructuring transportation, and form partnerships involving developed and developing countries for the purpose of creating and implementing new approaches to sustainable transportation.

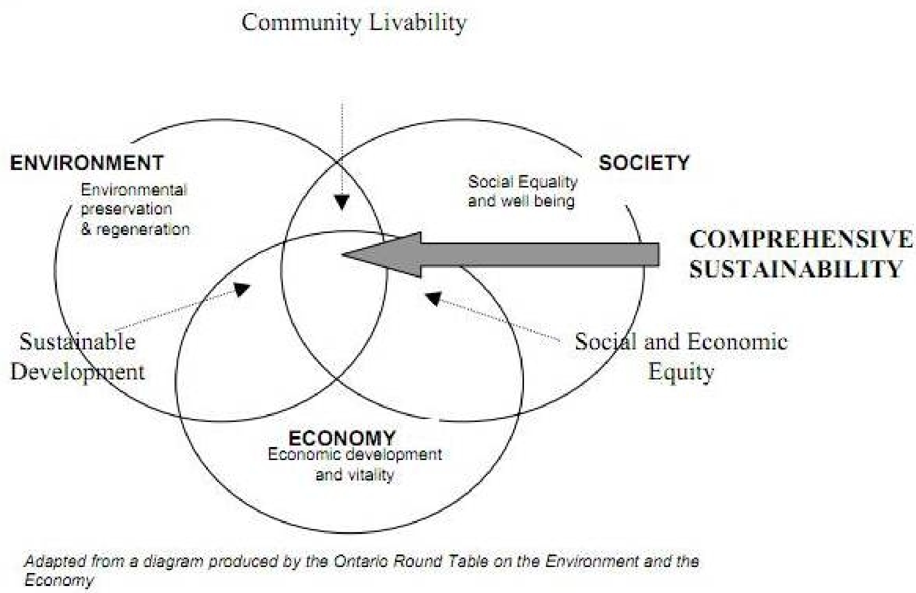
Source: Organisation for Economic Co-Operation and Development (OECD), 1997.

As a response to the challenge of developing the concept of sustainable transportation, definitions based on the principles agreed at the Vancouver Conference in 1996 were developed by the Center for Sustainable Transportation in Canada (CST) in 1997, which was also later adapted by the Council of the European Union in 2001. A sustainable transportation system has the following characteristics:

- "Allows the basic access and development needs of individuals, companies and society to be met safely and in a manner consistent with human and ecosystem and health, and promotes equity within and between successive generations;
- Is affordable, operates fairly and efficiently, offers a choice of transport mode and supports a competitive economy, as well as balanced regional development; and
- Limits emissions and waste within the planet's ability to absorb them, uses renewable resourced at or below their rates of generation, and uses non-renewable resources at or below rates of development of renewable substitutes, while

minimizing the impact on the use of land and the generation of noise" (CST, 2002; CST, 2005; Litman, 2007; Greg, Kimble, Nellthorp, & Kelly, 2010).

Furthermore, CST also developed a visual representation of the linkages between economy, society and the environment depicting the relationships between the sustainability goals of economic development and vitality, social equality and well-being, and environmental preservation and regeneration. Figure 1.1 presents the convergence of these over-arching goals.



Source: The Centre for Sustainable Transportation (CST), 2002

Figure 1.1: Visual representation of the three goals of sustainable transportation

The economy describes the available resources and how resources are organized to meet human needs and goals. Society, on the one hand, is the composite of human interactions and how they are organized. The sustainability of societies is a necessary condition for meeting human needs. Finally, the environment refers to the surroundings of humans and other life forms that support them and limits their activity according to basic physical laws (CST, 2002). The goal of sustainable transportation is to address transport needs by providing access to affordable and efficient transport mode choices that supports economic development and vitality, environmental preservation and regeneration, and social equality and well-being (CST, 2002; CST, 2005). While many definitions, indicators and metrics of sustainable transportation have emerged (Jeon & Amekudzi, 2005; Hall, 2006), there is a general consensus that a sustainable transportation system should address all environmental, social and economic externalities associated with transportation.

Metropolitan growth theories also support the notion of sustainability and sustainable transportation. Urban planners and local officials are vested in the preservation and revitalization of central cities that have been affected by suburbanization and rail transit is one of the transport mechanisms used to facilitate the mobility of the middle working class from their home to their workplace in center cities. Rail transit is also promoted for its economic development potential and its potential to decrease congestion, as well as pollution. Also, rail transit is politically acceptable compared to highway construction in some cases because of its smaller environmental/ecological footprint on urban areas. Finally, rail transit supports smart growth, which regards transit-based accessibility as a key element in fostering high density development patterns that define modern cities today (Giuliano, 2004).

Environmentally conscious transportation (Meyer, 2008) affects the intergenerational aspect of sustainable development by making resources available for use by future generations. In this study, estimating the impact of light rail presence on the environmental sustainability of urban areas addresses the perception of whether light rail helps lower air pollution, energy use and greenhouse gas emissions in the area. Understanding these environmental sustainability goals feeds into the comprehensive understanding of sustainable transportation that is used as a policy framework in transit planning.

Significance of the Study

The assessment of light rail transit (LRT) systems in the literature has been focused on the analyses of the attributes of light rail operations, feasibility studies, capacity studies, efficiency and effectiveness. The approach used by these studies mostly focuses on case studies or comparative analyses of different light rail systems in the US using sets of criteria or goals. Conclusions from these studies mostly yield case-specific results and are dependent on the variability of the conditions and operations associated with existing operational LRT systems (Greenberg, 2005). An analysis of the viability of light rail systems under the sustainability framework leads to a better understanding of how light rail influences environmental sustainability in urban areas.

The primary contribution of this study will be an empirical assessment of the impact of light rail presence on environmental sustainability indicators. Because sustainable development is grounded on concerns on the impact of human activities – including transportation – on the environment, this study focuses on the environmental aspect of sustainability. While studies on the social and economic aspects of sustainable transportation are equally important, there is a research gap in analyzing the impact of passenger rail transit modes to the environmental sustainability in the urbanized area. Focusing on environmental sustainability, a more specific explanation will be provided on whether or not the perception for the benefits provided by light rail is valid.

Aside from enhancing the current literature on the environmental sustainability of light rail systems, the results of the analysis assess the viability of the selected indicators for environmental sustainability goals and identify factors that influence environmental sustainability. By identifying influential factors, policy can be directed towards improving these factors so that the benefit of environmental sustainability is achieved. The results of analysis can be used to aid policy formulation and analysis through more study of the significant factors that influence environmental sustainability.

The assessment of the impact of light rail presence on environmental sustainability can also be a starting point to develop an appropriate policy instrument for evaluating the light rail as a viable and sustainable transit option. Although this study only focuses primarily on the environmental aspect, the results of the study can also enrich the existing literature on sustainable transportation and how light rail systems are evaluated. The methodology used for analyzing the impact of light rail on environmental sustainability can also be applied to economic and social sustainability outcomes in future research endeavors. This study can also help strengthen policy discussions that relate to the principles of sustainable transportation.

Overview of the Dissertation Chapters

The objective of this dissertation is to understand how light rail presence affects environmental sustainability in urban areas. Environmental sustainability indicators include measurements for minimizing air pollution, energy resource use and greenhouse gas emissions. The study is focused on the environmental aspect of sustainable transportation and will also include the identification of indicators that will best describe environmental sustainability.

To undertake this study on determining the influence of light rail on environmental sustainability, this dissertation is organized into six chapters that cover the background of the study, the literature review, the methodology, and the presentation of the results of the analysis. A discussion of the results and policy implications will also be included. The concluding chapter will provide the major conclusions of the study and recommendations for future directions for research on the assessment of the impact of light rail on environmental sustainability.

Chapter 1 serves as the introductory chapter, which provides the rationale for the study, the statement of the problem and a brief discussion on sustainability and sustainable transportation as the theoretical basis for this study. Chapter 1 also states the research goals, the research questions and the research strategy for this study, the significance of the study, and the scope and limitations of entire research study. Chapter 2 provides the review of related literature on sustainability, sustainable development and sustainable transportation. The literature review also includes a review of previous studies on light rail transit systems and the issue of environmental sustainability assessment. Chapter 3 focuses on the methodology used in the study, including a discussion on the research design, the population and sample, variables to be used, data collection and preparation, as well as the methods used for analysis. Chapter 4 presents the analysis and the results while Chapter 5 provides a discussion of the results and the policy implications of the results of the study. Chapter 6 concludes the study and provides policy recommendations and suggestions for the future direction for research on environmental sustainability. This study is expected to provide insights on how light rail presence affects air quality, energy consumption and carbon dioxide emissions.

Determinants of these selected environmental sustainability indicators will also be identified in the study. The conclusions from this study are expected to aid policy formulation and analysis related to light rail, and also strengthen the discussions on the issues related to sustainable transportation.

CHAPTER 2: REVIEW OF RELATED LITERATURE

This chapter provides an expanded review of the concept of sustainable development from the definition provided by the Brundtland Commission (WCED, 1987) to a more comprehensive definition of sustainable transportation that covers economic, social and environmental goals. A discussion of the assessment of sustainable transportation and the development of selected indicator frameworks is included in this section followed by a more focused narrative on environmental sustainability. Finally, a discussion on studies pertaining to light rail transit systems will also be included in this chapter. Based on these discussions on pertinent literature on environmental sustainability and light rail systems, the rationale for the formulation of the research question concludes this chapter.

Defining Sustainable Transportation

Sustainability emerged from discussions organized by the United Nations World Commission on Environment and Development (WCED) in 1987, the United Nations Conference on Environment and Development (UNCED) in 1992, and in succeeding initiatives by the Organisation for Economic Co-Operation and Development (OECD) in the late 1990s. The WCED, more popularly known as the Brundtland Commission, defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). This definition assumed that the existing natural environments can support the increasing human population needs of the present and future generations. In addition, sustainability in this sense addresses the issue of equity and equity among populations in present and future generations, and encompasses the general understanding of economic, environmental and social aspects. However, criticism for this definition indicates that sustainability in this sense failed to consider the earth's carrying capacity, ecological stability and geographical security (Daly, 1990; Rees, 1995). By the 1990s, following the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil in 1992, the attending national governments endorsed Agenda 21, which states that "various sectors of human activity should develop in a sustainable manner". Sustainable transportation, hence, became the expression of sustainable development in the transport sector, which became the focus of various international efforts for developing the concept's definition (OECD, 1997).

To respond to concerns that transportation provides challenges to the sustainable development agenda, OECD, together with the Government of Canada, organized a conference on sustainable transportation on March 24 to 27, 1996 in Vancouver, British Columbia. Key transportation stakeholders from 25 nations developed a vision for sustainable transportation, bringing to the discussion findings from a series of meetings between 1990 and 1994 that were organized by the OECD, the International Energy Agency (IEA), the European Conference of Ministers of Transport (ECMT) and others agencies and governments. These meetings underlined technical solutions, such as the development of low consumption and low emission automobiles, promotion of clean fuel for cars, use of alternative fuel vehicles and provision for public transit as alternative transportation options. With growing consensus to bring sustainable transportation on the policy agenda, the Vancouver Conference brought together around 400 automobile and alternative vehicle manufacturers, fuel producers, regional and local planners, and government officials to develop a vision for sustainable transport. Participants in the conference acknowledged that the challenge is to find ways of meeting transportation needs that are environmentally sound, socially equitable and economically viable. A set of sustainable transportation principles (Table 1-3) was presented and endorsed, which covered principles of access, decision-making, urban planning, environmental protection, and economic viability.

In the Vancouver Conference, a review of the conditions for sustainable transportation under the OECD's Environmentally Sustainable Transport (EST) project in 1996 also yielded a preliminary qualitative definition of an environmentally sustainable transport (EST). An environmentally sustainable transportation system is "transportation that does not endanger public health or ecosystems and meets mobility needs consistent with (a) use of renewable resources at below their rates of regeneration and (b) use of non-renewable resources at below the rates of development of renewable substitutes" (OECD, 1997). This definition, however, focused only on addressing the environmental goal of sustainable development. The economic and social goals were not been considered at this 1997 conference.

Sustainable transportation has also been defined as "satisfying current transport and mobility needs without compromising the ability of future generations to meet their needs" (Black W. R., 1996). This definition is a broad representation of the transport sector based on the definition of sustainability from the Brundtland Commission report. Another definition specifies more details but this is also broadly based on the Brundtland

Commission: “a sustainable transportation system is one in which fuel consumption, vehicle emissions, safety, congestion and social and economic access are at such levels that they can be sustained into the indefinite future without compromising the ability of future generations of people throughout the world to meet their transportation needs (Richardson, 1999).

Finally, the United Nations also proposed that sustainable development when applied to the transportation sector has to secure a balance between equity, efficiency and the capacity to answer the needs of future generations. This role implies securing the energy supply, reflecting the costs of non-renewable resources in transport vehicle operations, creating responsive and effective markets, and adopting production processes respective of the environment by eliminating externalities that are detrimental to future generations (Rodrigue, Comtois, & Slack, 2006).

Given all the definitions of sustainable transportation that have been presented, a comprehensive definition of sustainable transportation that captures all the aspects of the economic, social and environmental goals of sustainability is presented on Table 2.1. This table addresses specific issues of each sustainable transportation goal and provides detailed definitions that describe these different aspects. Economic sustainability covers affordability, efficiency and social cost, while social sustainability focuses on access, safety, and both intragenerational and intergenerational equity. Finally, environmental sustainability captures issues on health and environmental damage, standards, noise, land use, emissions and waste, renewable resources, non-renewable resources, energy and recycling (Hall, 2006). This comprehensive definition of sustainable transportation guides this study in identifying parameters that describes sustainability urban areas.

Table 2.1: A comprehensive definition of sustainable transportation

Sustainability Goal	Transportation Issue	Definition (A Sustainable Transportation …)
ECONOMY	Affordability	• Is affordable;
	Efficiency	• Operates efficiently to support a competitive economy; and
	Social Cost	• Ensures that users pay the full social and environmental costs for their transportation decisions.
EQUITY/SOCIETY	Access	• Provides access to goods, resources, and services while reducing the need to travel;
	Safety	• Operates safely; • Ensures the secure movement of people and goods;
	Intragenerational Equity	• Promoted equity between societies and groups within the current generation, specifically in relation to concerns for environmental justice; and
	Intergenerational Equity	• Promotes equity between generations.
ENVIRONMENT	Health and environmental damage	• Minimizes activities that cause serious public health concerns and damage to the environment;
	Standards	• Maintains high environmental quality and human health standards throughout urban and rural areas;
	Noise	• Minimizes the production of noise;
	Land Use	• Minimizes the use of land;
	Emissions and Waste	• Limits emissions and waste to levels within the planet's ability to absorb them, and does not aggravate adverse global phenomena including climate change, stratospheric ozone depletion, and the spread of persistent organic pollutants;
	Renewable Resources	• Ensures that renewable resources are managed and used in ways that do not diminish the capacity of ecological systems to continue providing these resources;
	Non-renewable resources	• Ensures that non-renewable resources are used at or below the rate of development of renewable substitutes;
	Energy	• Is powered by renewable energy sources; and
	Recycling	• Reuses and recycles its components.

Source: Hall, 2006

Assessment and Measurement of Sustainable Transportation

The assessment and measurement of sustainable transportation is as elusive as finding a standard definition for the concepts of sustainability and sustainable development. These definitions also evolved from attempts to quantify general definitions and assign various measurable indicators. This section provides a discussion on selected tools and approaches for sustainability assessment. These tools and approaches were designed to aid policy decision-making and to promote sustainable transportation.

Sustainability assessment is initially driven by environmental impact assessments (EIAs) and strategic environmental assessments (SEAs). EIAs are typically applied to project proposals and SEAs are applied to policies, plans and programs (PPPs). EIA-driven integrated assessments aim to identify the environment, social and economic impacts of a proposal after a proposal has been designed. Resulting impacts are then compared with baseline conditions to determine whether or not they are acceptable. SEA-driven assessments (also referred to as objectives-led integrated assessments) help determine the extent to which a proposal contributes to defined environmental, social and economic goals before a proposal has been designed and to determine the "best" available option in terms of meeting these goals. Both types of assessments reflect the vision of sustainability but do not determine whether or not an initiative is actually sustainable. An "assessment for sustainability" approach is proposed that requires a clear concept of sustainability as a societal goal is defined by criteria against which the assessment is conducted, and which separates sustainable outcomes from unsustainable ones. Although this concept has been defined in theory, this concept is not always evident, nor is it applied empirically in practice (Pope, Annandale, & Morrison-Saunders, 2004).

A number of indicators for sustainable transportation have been developed by various agencies, organizations or programs. Table 2-2 presents a comprehensive list of these initiatives and their suggested lists of sustainable transportation themes and indicators for measurement.

Table 2.2: List of sustainable transportation themes/indicators developed by agencies, organizations or programs

Agency/Organization/Program	Sustainable Transportation Themes/Criteria/Outcomes
Environmentally Sustainable Transport (EST)	Emissions from Carbon Dioxide, Nitrogen Dioxide, Volatile Organic Compounds and Particulates ; Noise ; Land Use/Land Take
Mobility 2001 and 2030	Accessibility; Financial Outlay required of users; travel time; Reliability; Safety; Security; Greenhouse Gas Emissions; Impact on the Environment and on public-well-being; Resource use; Equity implications; Impact on public revenues and expenditures; Prospective rate of return to private business
KonSULT, the Knowledgebase on Sustainable Urban Land Use and Transport	Economic efficiency; Environmental protection; Safety; Accessibility; Sustainability; Economic regeneration; Finance; Equity
TERM (Transport and Environment Reporting Mechanism	Transport and Environment Performance (Environmental consequences of Transport, transport demand and intensity); Determinants of the Transport/Environment System (Spatial Planning and Accessibility, Supply of Transport Infrastructure and Services, transport Costs and Prices, Technology and Utilisation Efficiency, Management Integration)
SUMMA (Sustainable Mobility, Policy Measures and Assessment)	Accessibility; Transport Operation Costs; Productivity/Efficiency; Costs to Economy; Benefits to Economy; Resource Use; Direct Ecological Intrusion; Emission to Air; Emissions to Soil and Water; Noise; Waste; Accessibility and Affordability (Users); Safety and Security; Fitness and Health; Liveability and Amenity; Equity; Social Cohesion; Working Conditions in Transport Sector
Sustainable Transportation Performance Indicators (STPI)	Environmental and health consequences of Transport; Transport activity; Land use urban form, and accessibility; Supply of transport infrastructure and services; Transportation expenditures and pricing, Technology adoption; Implementation and monitoring

Table 2.2: (continued)

Agency/Organization/Program	Sustainable Transportation Themes/Criteria/Outcomes
UN Economic Commission for Europe (UN/ECE) – Sustainable Urban Transport Indicators	Reduction of locally-acting and globally acting emissions; Urban transport safety; Access/accessibility Efficiency in public transport; Noise reduction; Integration of land use and urban transport planning and transport services/environmentally-friendly zoning; Modal shift (away from car use); Improved efficiency in urban freight transport; Preservation of cultural heritage/visual quality/urban livability/citizen satisfaction; Internalization of external costs/price signals
US Department of Transportation (USDOT) National Transportation System (NTS) Performance Measures	Transportation System Performance (Accessibility, Quality of Service, Efficiency); External Impacts and Outcomes (Economic Health and Competitiveness, Social Equity, Mobility, Quality of Life, Security, Safety, Environment, Energy); Description of Supply and Demand (Demand: Population, Households, Personal Travel, Freight Movements; Supply: Highway Infrastructure, Mass Transportation Services, Freight Transportation Services)
US DOT Environmental Performance Measures	Wetlands Protection: Hazardous Waste; Airport Noise Exposure; Toxic Materials; Maritime Oil Spills; Emissions; Livable Communities/Transit Service; Environmental Justice; Greenhouse Gas Emissions; Energy; Fisheries Protection

Source: Hall, 2006

There are also a number of evaluation methodologies that have been developed and used by the state and provincial DOTs and metropolitan planning organizations for decision-making and promotion of sustainable transportation. The traditional set of economic tools that transportation planners and decision-makers use include benefit-cost analysis (BCA), economic impact analysis, life cycle costs analysis (LCCA), and cost-effectiveness analysis (CEA). Other techniques used include travel demand and air quality models, risk assessments, environmental impact assessments (EIAs) and multi-criteria approaches (MCA) (Hall, 2006). Other methodologies also include scenario planning, graphical models, system dynamics approaches, economic-based models, integrated transportation and land use models, and simulation and decision analysis models (Jeon, 2007). There are also some quantitative sustainability models that have been applied in some European countries, such as SPARTACUS (Systems for Planning and Research in Towns and Cities for Urban Sustainability) and ESCOT (Economic Assessment of Sustainability Policies of Transport) (Jeon, 2007).

Focus on Environmental Sustainability Assessment

With respect to rail systems, several studies outline direct and indirect environmental effects of rail. Table 2.3 presents some of the impact of railways previously identified prior to the discussion of a sustainability agenda (Carpenter, 1994; Fietelson, 1994).

Table 2.3: Environmental impacts of railways

Impacts	Direct Impacts	Secondary Impacts
Impacts on People:		
Social Impacts	Jobs, housing facilities	Equity/inequity; public perception; public participation
Noise and vibration	Disturbance at line-side and near terminals;	Property values; Visual impacts of noise barriers
Air and water pollution	Diesel engines; Accident risks	Power stations; Changes to Drainage
Visual impacts	Obstruction; Intrusion	View from trains
Construction impacts	Disturbance by dust, noise and traffic	Disposal of spoil; Transport of materials
Impacts on resources:		
Energy use and climatic change	Depends on efficient use of fuels	Depends on sources of electric power
Material assets	Manufacture of rolling stock and equipment	Disposal of old equipment; Land reclamation
Land resources:		
General Use	Land take in long strips of undervalued resources	Partition or severance of:
Residential	Property loss	- Communities, roads
Commercial	Production loss	- Factory complexes
Agriculture	Production loss	- Farms
Nature conservation	Loss/disturbance of habitat	- Wildlife corridors
Cultural Heritage	Loss of historic features	- Historic units or related groups

Table 2.3: (continued)

Impacts	Direct Impacts	Secondary Impacts
Amenity	Land take	- Paths, golf links, playing fields
Scenic Landscape	Intrusion; modifications to features	Effects on distant active land forms

Sources: Carpenter, 1994; Fietelson, 1994.

In 1996, the U.S. Environmental Protection Agency (EPA) developed quantitative national estimates of the impacts of highway, rail, aviation and maritime transport on the environment. This assessment addressed the full life cycle cost of transportation, from construction of infrastructure to the manufacture of vehicles and parts. The study utilized a categorization scheme that focuses on the grouping of the impacts of basic transportation activities affecting the environment. The basic transportation activities include the following: a) infrastructure construction, maintenance, and abandonment; b) vehicle and parts manufacture; c) vehicle travel; d) vehicle maintenance and support; and e) disposal of used vehicles and parts. This categorization shifts the focus on transportation activities, rather than on impacts on the forms of environment such as air, water and land resources (Environmental Protection Agency, 1996). However, while this study succeeded in identifying environmental impact indicators, most of the indicators that were identified have limitations on the availability of data in the transportation statistics that are currently being collected by government and other statistical agencies. In summary, the EPA's assessment was initiated on a completely different empirical basis that may not be easily replicated and a completely different analytical approach. There has been no other subsequent EPA study on this topic that can be found in the literature.

At the national level, however, an environmental sustainability index developed by the Yale Center for Environmental Law and Policy was formulated based on five fundamental components of sustainability: environmental systems, environmental stresses, human vulnerability to environmental stresses, societal capacity to respond to environmental challenges, and global stewardship (Etsy, Levy, Srebotnjak, & De Sherbinin, 2005). By integrating datasets that consider natural resource endowments, historical pollution levels, environmental management efforts and capacity of the society to improve environmental performance, 21 indicators that describe environmental sustainability were identified. These indicators are: air quality, biodiversity, land, water quality, water quantity, reducing air pollution, reducing ecosystem stresses, reducing population growth, reducing waste and consumption pressures, reducing water stress, natural resource management, environmental health, basic human sustenance, reducing environment-related natural disaster vulnerability, environmental governance, eco-efficiency, private sector responsiveness, science and technology, participation in international collaborative efforts, greenhouse gas emissions, and reducing trans-boundary environmental pressures (Etsy, Levy, Srebotnjak, & De Sherbinin, 2005). While the study boasts of the richness of specific environmental impact indicators, the study only focuses on one year, based on national data collected from different countries. Factors that explained environmental sustainability using this approach are too broad, and may only be used to explain environmental sustainability in general terms.

Urban environmental sustainability metrics were also defined covering issues that affect urban areas such as air, water solids, transportation, energy, resource use, population, urban ecology, livability and general environmental management (Shane &

Graedel, 2000). This study identified metrics that were used on a study of Vancouver, Canada, whose government has embraced sustainability in their urban planning and policy development. The study provided a good starting point for exploring other metrics that are issue-based and applicable to urban areas.

Finally, recognizing different ways and approaches in analyzing environmental sustainability, a new framework is being proposed that takes into account causal chains on environmental issues in the transport sector (Joumard, 2011; Joumard, Gudmundsson, & Folkeson, 2011). There are forty nine (49) identified causal chains in the study that covers the following environmental issues: noise and vibrations, accidents, air pollution, soil and water pollution, impacts on land, non-renewable resource use and waste handling, greenhouse effects, and other impacts. While this approach captures several environmental aspects, an empirical study needs to be done to demonstrate the assessment of environmental sustainability. The study is still conceptual but it provides ideas for future research on environmental sustainability, whether applied to public transit options or as applied to urban areas that currently provide public transit services.

Relevant Studies on Light Rail Transit Systems

Existing relevant light rail studies in the literature focus on the attributes of LRT operations, capacity studies, efficiency and effectiveness. In terms of its desirable characteristics, LRT systems are quiet, and environmentally unobtrusive. LRT is electrically propelled, so the “carbon footprint” of petrochemical fuels is shifted from the private owned vehicles (POVs), freight and commercial carriers to the electrical power grid, which is usually in areas some distance from urban centers. They operate effectively along available railroad tracks and sometimes on street medians. LRT is also cheaper and less disruptive, easier to build than heavy rail, and also lacks exhaust fumes. LRT runs on slower speeds than heavy rail and is designed for pedestrian settings (Cervero, 1984). Aside from these characteristics, LRT is also competitively compared with automobiles in terms of image and functionality. It is also cheaper to build than new highways. It is attractive to both residential and commercial development, and is able to “green the city” (Newman & Kenworthy, 1999). LRT is also superior to buses in terms of riding comfort, vehicle performance and system image (Vuchic, 1999).

There are many studies that have been conducted to assess the performance of light rail systems. In addition to the pros and cons of investing in light rail systems, analysis of impacts on land use, residential location and employment location have also been conducted (Bhatta & Drennan, 2003; Giuliano, 2004). Light rail systems have also been compared to bus rapid transit systems in terms of operating costs, impacts on travel, capital costs, and speed (Semmens, 2006), value for money, service capacity, affordability, relative flexibility and network coverage (Hensher, 2007). A few other studies were also conducted focusing on planning for the operation of LRT systems, including urban rail terminal location (Horner & Grubesic, 2001) as well as decision making processes involving local governments (De Bruijn & Veeneman, 2009).

A study on light rail systems in Europe in comparison with bus systems demonstrate that there are many system-wide benefits of having LRT systems compared to only having bus systems (Hass-Klau, Crampton, & Benjari, 2004). Benefits that were identified in the study were higher public transport patronage, more passengers transported per hour compared to standard buses, low noise and pollution, running comfort, better urban design and slightly cheaper cost than buses. In another study that compared 130 US cities with and without rail, those with rail systems have lower traffic congestion costs, lower traffic fatalities, lower consumer transport expenditures, higher public transport ridership, higher operating costs per passenger mile and higher public transport service cost recovery (Litman, 2004). The findings from these studies support the findings from an international study on the significance of rail in higher income cities, where cities with strong rail features have greater wealth and more cost-effective urban transport systems. In relation to environmental factors, the findings of this international study also yield these conclusions: a) per capita use of energy increases in private passenger transport as cities are less rail-oriented, and b) per capita generation of local smog producing emissions from transport are higher in cities with no rail than in cities with strong rail presence (Kenworthy, 2008).

A more recent study on light rail transit was conducted in Hamilton, Canada, where health, environmental and economic impacts were reviewed (Topalovic, Carter, Topalovic, & Krantzberg, 2012).Findings indicate that LRT in medium sized growing cities like Hamilton are considered as a catalyst for transit-oriented, high density and mixed use development. In addition, their findings conclude that LRT is an economically sound investment opportunity, and a catalyst for social change that helps improve health, environment and connectivity in the community. From this study alone, it appears that LRT concurs with the sustainable transportation agenda, although its findings are concentrated on the economic benefits of light rail rather than on environmental aspects. A related study on Hamilton’s light rail modeled the relationship between the construction of an LRT network and land use, transportation and other activities (Lavery & Kanaroglou, 2012). They find that construction of an LRT network alone is not sufficient causation for economic development and transit modal shares.

General Findings of the Literature Review

The literature review tells us that most of the studies cover concepts, definitions and themes that relate to sustainable transportation. There are studies that pertain to the measurement of sustainable transportation and environmental sustainability. While there are relevant studies pertaining to light rail, most of these studies are case studies and have specific application for selected urban areas. Some literature on rail and light rail focus on advantages and disadvantages of light rail but findings are biased towards other public transit modes like buses, and still with automobile use. Studies on the factors that contribute to environmental sustainability at the urban level are limited, and not entirely focused on light rail.

Based on the foregoing discussion of the related literature on environmental sustainability and light rail systems, there are limited empirical studies that directly focuses on the impact of the implementation of light rail transit systems on environmental sustainability, and even with comprehensive sustainability. A number of studies have been conducted providing for the assessment of light rail systems in terms of economic performance. A few of these studies focus on the environmental impacts and there have been limited studies that focus on light rail systems at an urban area level, specifically in the United States. Despite this gap in the literature, the more recent studies on environmental sustainability assessments provide a good starting point for setting the agenda for this research.

To address this gap in the literature, this research study proposes a more targeted approach to measure environmental sustainability by focusing on one aspect from the triple bottom line of sustainability. Since concerns on the unsustainability of existing transport system emerged from growth in transport activities that affect the environment, this study will focus on the environmental aspect of sustainability. From the definition of environmental sustainability, measurable goals are selected together with corresponding indicators available from the statistical system. From the findings of the literature, possible determinants that influence environmental sustainability are also included in the study.

Looking back into the goals of environmental sustainability (Hall, 2006), the following goals are selected: to minimize air pollution, energy use and greenhouse gas emissions. Indicators to be used as outcome variables for this study are the variables that best represent environmental sustainability include the air quality index, energy intensity, energy consumption per capita, carbon dioxide intensity and carbon dioxide emissions per capita. The air quality index serves as a measure of air quality in the area, while the indicator for energy consumption is the sum of all transit fuels consumed by transit agencies for a year. Greenhouse gas emissions can be measured by converting the energy use in urban areas into carbon dioxide equivalents. By identifying these measurement variables, outcome indicators that describe environmental sustainability can be derived.

Determinants of environmental sustainability can be many different factors that lead to environmental impacts. Urban densities generally affect the environment conditions in an area, hence, population density, housing density and employment establishment density can be tested as a determinant for environmental sustainability. Ridership also tends to affect the performance of transit agencies – more ridership, more efficiency. However, in the context of an urban area, the relationship may not be the same. Hence, ridership is also included as a possible determinant of environmental sustainability. The service route, operating expenses and the number of vehicles used at maximum service will also be included as factors. These light rail transit system characteristics may also contribute to environmental sustainability. The analysis of the relationship among these variables, with corresponding measurement indicators at the urban area level, can explain how light rail contributes to the environmental sustainability in urban areas.

The methods used for analysis and the research design for analyzing the impact of light rail on environmental sustainability indicators are described in the succeeding chapter.

CHAPTER 3: METHODOLOGY

The goal of the study is to determine how light rail presence affects environmental sustainability in urban areas. This study also seeks to identify relevant factors among light rail, public transit and urban area characteristics that influence environmental sustainability in urban areas. The research questions for this study are expressed as follows:

1. How does light rail presence affect environmental sustainability indicators in urban areas?
2. For urban areas that have light rail systems, how do light rail, public transit, and urban area characteristics affect environmental sustainability indicators?

The two research questions articulate the analytical framework for developing a model for assessment of environmental sustainability indicators in urban areas. This chapter discusses the research design, the methods of analysis, model specifications, the variables and the sources of data used for analysis.

Research Design

The research design for this study is based on an ex-post program evaluation approach, where light rail transit is evaluated as an existing operational program. The units of analysis for this study are the urban areas classified and defined by the Census Bureau – geographical areas that have 50,000 or more population (Department of Commerce, 2011). As identified in the 2010 Census population survey, the study will look into 486 urbanized areas in all US states (including District of Columbia) that are served by public transportation. The 486 urbanized areas comprise the population for this study. Among these areas, there are 27 urbanized areas that have light rail services in 2011 (as presented in Table 1.2). These urban areas are referred to as the treatment group. The remaining 459 urban areas in the population provides other forms of public transportation services, such as motorized buses of various capacities, demand response services, and other forms of passenger rail – heavy rail and commuter rail transit. The 459 urban areas that have no light rail services are included in the control group.

Each urbanized area is considered as one case observation, and tracks the trend of factors that can influence environmental sustainability from 2000 to 2011. The control group (areas that do not have light rail) is included in the study to provide a counterfactual analysis for comparing the conditions where there is no light rail system present. The treatment group (urban areas that have light rail) have data that represent characteristics of light rail operations that may indicate some influence on environmental sustainability indicators. Using a series of regression analysis, factors that explain environmental sustainability can be predicted taking into account the observations for both areas with light rail and no light rail from through time. The model for this program evaluation approach is illustrated in the following equation:

$$y_{it} = \alpha + \beta_i X_{it} + \beta_T T_{it} + \beta_T C_{it} + u_{it} \qquad \text{(Equation 3.1)}$$

where $\boldsymbol{y_{it}}$ is the dependent variable (representing the selected environmental sustainability goals) per urbanized area through time, and Xi_t represents explanatory/independent variables that affect environmental sustainability. The term

T_{it} represents the variables for the treatment group, C_{it} represents variables for the control group and $u_{it,}$ represents other individual, time-specific effects.

Methods of Analysis

This study will use regression, statistical analysis and impact analysis to address the research questions posed in this study and to provide insights on how light rail presence affects environmental sustainability.

Descriptive statistics for each of these variables are generated and presented to provide an overview of the types of data that were used in the analysis. Descriptive statistics include mean, standard deviation, minimum and maximum values, as well as the number of observations used and missing data.

To determine the individual relationships among dependent and independent variables, bivariate or simple regressions are conducted. Bivariate regressions only have one influence (independent variable) and one outcome (dependent variable). The results of the bivariate regressions provide the direction of the relationships among variables. The results will also indicate whether or not each of the bivariate models is significant, and whether the resulting models are good predictor models for environmental sustainability.

To build the models for environmental sustainability, multiple regression or fit model analysis using standard least squares is used. Multiple regressions include more than one influential variable that may affect the outcome variable. The results of the regression analysis will provide a summary of fit (through the R-square values), an analysis of variance (including the F-test, which indicates the significance of the model) and parameter estimates. Using standard least squares, the parameter estimates show significant independent variables that affect the selected environmental sustainability indicators. For this study, two types of regression analysis techniques are used: ordinary least squares and fixed effects. Given that panel data is used in the analysis, the "year effect" is estimated through the fixed effects approach. The year effect refers to the aggregate effect of unobserved factors that affect the dependent variable equally in a particular year.

Figure 3.1 shows the analysis map for the regression analysis to address the two research questions.

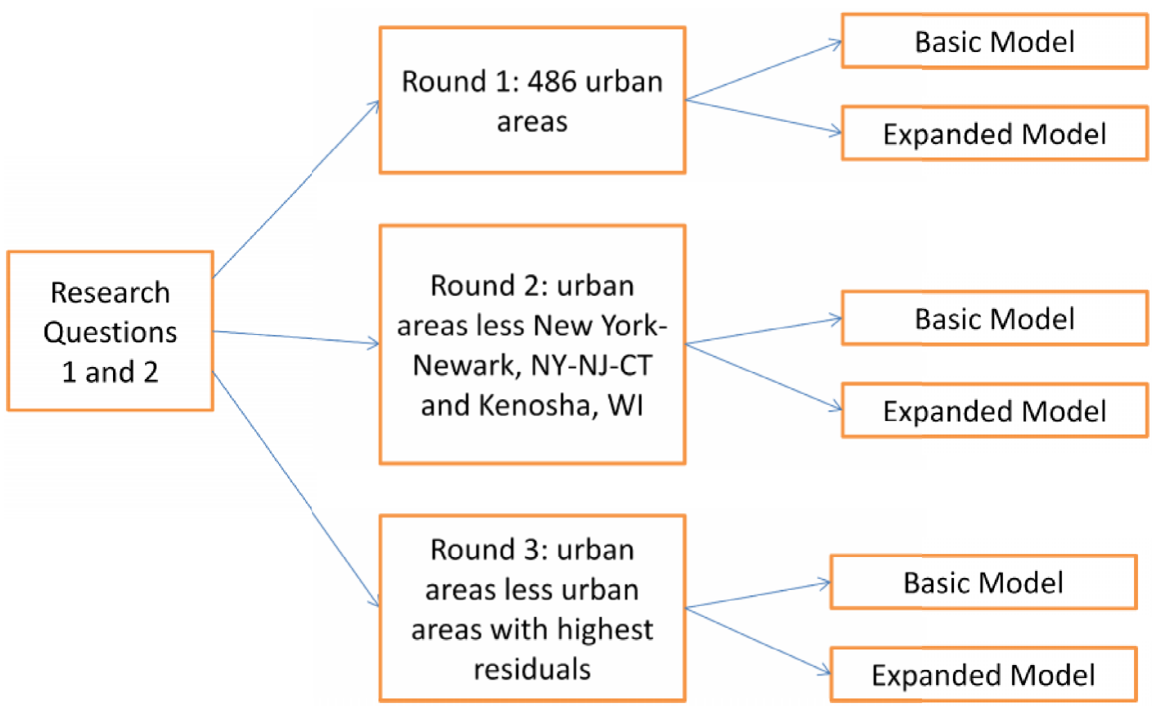


Figure 3.1: Analysis map for the assessment of the environmental sustainability of light rail transit in urban areas

Each research question will be addressed through a series of regression analysis. Each question will be analyzed three rounds of regression analysis which covered three types of datasets. The first round of regression analysis covers the dataset for all 486 urban areas included in the study. The second and the third rounds of regression analyses cover additional regression analysis using dataset that removed two types of outliers. Outliers in the dataset affect the results of the regression for the selected environmental sustainability indicators, but removing them may strengthen and improve the regression results. Two kinds of outliers are removed in the second and third datasets. The second dataset removed urban areas with light rail transit that had the lowest and highest service area populations. These urban areas refer to the New York-Newark, NY-NJ-CT urban area, which has the largest service area population, and Kenosha, WI, which has the lowest service area population. The third dataset comprises the urban areas less the urban areas with the highest residuals from the results of the first round of regression analysis. Among all urban areas, in the basic model, Phoenix-Mesa, AZ has the highest residuals for air quality index, while Blacksburg, VA has the highest residuals for energy intensity and CO2 intensity. Hilton Head Island, SC has the highest residuals for energy consumption per capita and CO2 emissions per capita. These three urban areas were removed from the dataset for the third round of regressions for the basic model. For the expanded model, Phoenix-Mesa, AZ and Blacksburg, VA have the highest residuals for air quality index, and for energy intensity and CO2 intensity, respectively. Highest residuals for energy consumption per capita and CO2 emissions per capita are both from the Boston, MA-NH-RI urban area. The three urban areas were removed from the dataset for the expanded model of the third round of regressions.

All three types of dataset are analyzed through three rounds of regression. Each round of regression is assessed through two types of models: basic and expanded models. The model with the highest variances explained by the independent variables (the model with the highest R-square) will be used for an impact analysis to demonstrate how the actual values and predicted values change when some of the variables and characteristics change. Changes that are tested in this study include:

1) Change in the number of urban areas with light rail presence based on size of the urban areas; and

2) Change in level of light rail ridership.

The classification for the size of the urban areas is based on the urban area classification used by the National Transit Database, as follows:

a) Small size urban areas – urban areas with population less than 200,000;

b) Medium size urban areas – urban areas with population greater than 200,000;

c) large size urban areas – urban areas with population greater than 1 million.

For changes in light rail transit ridership, a 25 percent, 50 percent, 75 percent and 100 percent increase from the actual light rail ridership is assumed. The average actual and the average predicted values for each selected environmental sustainability indicators are compared with the average predicted values for changes in light rail presence in urban areas and light rail ridership. The impact analysis will generate additional explanations of the relationship between significant independent variables and selected environmental sustainability indicators.

Model Specifications

The regression analysis for each selected environmental sustainability indicator will be presented in two models: basic or expanded, as described in the research design. Each of the selected environmental sustainability indicators serves as dependent variables that represent the outcome for the analysis. The first part of the analysis includes analysis for all urban areas, while the second part includes analysis of urban areas that have light rail. The model specifications for the analysis are listed as follows:

A. For All Urban Areas, 2000-2011, for each dependent variable (y):

1. Basic Model:

$$y_{it} = f(year, lrt, hrt, crt, interaction\ terms) \qquad \text{(Equation 3.2)}$$

where *y* refers to the selected environmental sustainability indicator, such as a) air quality index, b) energy intensity, c) energy consumption per capita, d) CO2 intensity and e) CO2 emissions per capita; *year* refers to year effects; *lrt* refers to light rail presence, *hrt* refers to heavy rail presence, *crt*, refers to commuter rail presence, and *interaction terms* refer to combinations of light rail, heavy rail and commuter rail in urban areas, such as a) light rail and commuter rail presence, b) light rail and heavy rail presence, c) heavy rail and commuter rail presence, and d) light rail, heavy rail, and commuter rail presence.

2. Expanded Model:

$$y_{it} = f(year, lrt, hrt, crt, interaction\ terms, urban\ area\ characteristics, public\ transit\ characteristics) \qquad \text{(Equation 3.3)}$$

where *y* refers to the selected environmental sustainability indicator, such as a) air quality index, b) energy intensity, c) energy consumption per capita, d) CO2 intensity and e) CO2 emissions per capita; *year* refers to year effects; *lrt* refers to light rail presence, *hrt* refers to heavy rail presence, *crt*, refers to commuter rail presence, and *interaction terms* refer to combinations of light rail, heavy rail and commuter rail in urban areas, such as a) light rail and commuter rail presence, b) light rail and heavy rail presence, c) heavy rail and commuter rail presence, and d) light rail, heavy rail, and commuter rail presence; *urban area characteristics* refer to the following: a) population density, b) housing density, and c) employment establishment density, and *public transit characteristics* refer to the following: a) ridership, b) directional route miles, c) operating expenses, and d) vehicles operating at maximum service.

B. For Urban Areas, 2000-2011, for each dependent variable (Y):

1. Basic Model

$$y_{it} = f(year, lrt\ characteristics) \qquad \text{(Equation 3.4)}$$

where *y* refers to the selected environmental sustainability indicator, such as a) air quality index, b) energy intensity, c) energy consumption per capita, d) CO2 intensity and e) CO2 emissions per capita; *year* refers to year effects; *lrt characteristics* refer to the following variables: a) light rail transit ridership; b) light rail transit directional route miles; c) light rail transit operating expenses; d) light rail transit vehicles operated at maximum service; e) light rail transit passenger miles; f) light rail transit energy consumption, and g) light rail transit CO2 emissions.

2. Expanded Model

$$y_{it} = f(year, lrt\ characteristics, urban\ area\ characteristics, public\ transit\ characteristics) \qquad \text{(Equation 3.5)}$$

where *y* refers to the selected environmental sustainability indicator, such as a) air quality index, b) energy intensity, c) energy consumption per capita, d) CO2 intensity and e) CO2 emissions per capita; *year* refers to year effects; *lrt characteristics* refer to the following variables: a) light rail transit ridership; b) light rail transit directional route miles; c) light rail transit operating expenses; d) light rail transit vehicles operated at maximum service; e) light rail transit passenger miles; f) light rail transit energy consumption, and g) light rail transit CO2 emissions; *urban area characteristics* refer to the following: a) population density, b) housing density, and c) employment establishment density, and *public transit characteristics* refer to the following: a) ridership, b) directional route miles, c) operating expenses, and d) vehicles operating at maximum service.

Variables

The variables that will be used in the study are described the following list:

- Environmental sustainability indicators – air quality, energy consumption and greenhouse gas emissions
- Light rail transit presence – whether or not light rail is present in the area
- Other forms of rail transit presence – commuter rail and heavy rail – whether or not rail transit is present in the area
- Urban area characteristics – population, housing units, employment establishments, and land area
- Light rail characteristics – ridership, operating expenses, directional route miles, number of vehicles at maximum service, energy consumption, carbon dioxide emissions
- Public transit characteristics - ridership, operating expenses, directional route miles, and number of vehicles at maximum service.

The dependent variables for this study are the environmental sustainability indicators – measured as air quality, energy consumption and greenhouse gas emissions. The dependent variable is the observed outcome for this study and the variable that is predicted based on the behavior of various determinants. The dependent variable for minimizing pollution is the air quality index. The dependent variables for energy consumption are energy intensity (which is the level of energy consumption (in British thermal units) per passenger miles traveled) and energy consumption per capita (energy consumption per population). The dependent variables for greenhouse gas emissions are carbon dioxide emissions intensity (which is the level of carbon dioxide in an urban area per output passenger miles traveled), and carbon dioxide emissions per capita (which is the level of carbon dioxide in the urban area per population).

The independent variables for this study are the light rail transit and other forms of rail transit presence in the urban area, the urban area characteristics and the selected light rail operations and performance indicators. Light rail presence is measured as a dichotomous ordinal data, either yes (1) or no (0), if light rail is present in the urban area. Commuter rail and heavy rail presence is also included measured as dichotomous ordinal data, either yes (1) or no (0), if commuter rail or heavy rail is present in the urban area. To include urban areas that have combinations of rail transit systems, interaction terms are created. Interaction terms for urban areas that have light rail, commuter rail, heavy rail, or a combination of all rail systems is considered in the analysis. Urban area characteristics in the analysis also include population density (number of people per area square mile), housing density (number of housing units per area square mile) and employment establishment density (number of employment establishments per area square mile). The context for including urban densities takes into consideration how urban form matters in the analysis – the more dense an area, how do urban areas with or without light rail affect environmental sustainability. Lastly, public transit characteristics included as independent variables are as follows:

a) total ridership in the area – regardless of what type of public transit mode people use,
b) total directional route miles for all transit modes,
c) total operating expenses for public transit, and
d) Total number of vehicles used at maximum service – in the case of rail, this refers to the number of rail passenger cars used at maximum service.

Light rail transit characteristics are also included in the study, as follows:

a) ridership for light rail,
b) directional route miles for light rail,
c) operating expenses for light rail,
d) the number of light rail vehicles used at maximum service,
e) light rail energy consumption, and
f) Light rail carbon dioxide emissions per urban area.

For the regressions analysis, the urban area characteristics and the public transit characteristics are used as control variables. Key variable of interest for the first research question is light rail presence in urban areas. For the second research question, significant variables emerge from the analysis and the direction of the relationship of these variables to the selected environmental sustainability indicators will be discussed.

Data Collection, Preparation and Analysis

The dataset used for this study is a panel dataset drawn from 486 urbanized areas in 50 U.S. states, including District of Columbia. The panel data contains observations from 12 years, from 2000 to 2011. The data used in this study is collected from:

a) the National Transit Database, compiled by the Federal Transit Administration,
b) Air Quality Reports from the Environmental Protection Agency,
c) Annual databases from the Energy Information Administration, and
d) Data from the U.S. Census Bureau.

The methods for collecting and preparing the data for analysis for each variable are explained as follows:

1. Air quality index

Data for air quality index is collected from the air quality index report produced by the EPA. The median air quality index was used in the study, which represents half of the daily air quality index values during the year that were less than or equal to the median value of the index. Table 3.1 presents the range of air quality index values and the levels of health concerns. The annual summary information for air quality index is generated from the air quality data website of the EPA: http://www.epa.gov/airdata/ad_rep_aqi.html.

Table 3.1: Air quality index values and levels of health concerns

Air quality index (AQI) Range Values	Levels of Health Concern	Explanation
0-50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.
51-100	Moderate	Air quality is acceptable, however, for some pollutants there may be a moderate health concern for a very small number of people.
101-150	Unhealthy for Sensitive Groups	People with lung disease, older adults and children are at a greater risk from exposure to ozone. Persons with heart and lung disease, older adults and children are at greater risk from the presence of particles in the air.
151-200	Unhealthy	Everyone may begin to experience some adverse health effects, and members of the sensitive groups may experience more serious effects.
201-300	Very Unhealthy	Everyone may experience more serious health effects.
301-500	Hazardous	The entire population is more likely to be affected.

Source: AirNow (Internet: http://www.airnow.gov/index.cfm?action=aqibasics.aqi)

2. Energy Consumption in British thermal units

Data for energy consumption is calculated by converting gallons of fuel consumed each year by transit agency as recorded in Table 17 of the National Transit Database. The gallons of fuel consumed by agencies are converted into British Thermal Units by multiplying the lower heating value for energy content for each fuel type. Table 3.2 presents the energy content heating values used to convert fuels into British thermal units. The energy content for each fuel type in the database is based on the fuel properties listed in the fuel comparison chart generated from the Alternative Fuels Data Center website of the Department of Energy: http://www.afdc.energy.gov/fuels/fuel_properties.php.

Table 3.2: Comparison of energy content by fuel types

Fuels	Energy Content	
	Lower Heating Value	Higher Heating Value
Gasoline	116,090 Btu/gallon	124,340 Btu/gallon
Diesel (No. 2)	128,450 Btu/gallon	137,380 Btu/gallon
Biodiesel (B100)	119,550 Btu/gallon	127,960 Btu/gallon
Compressed Natural Gas (CNG)	20,268 Btu/lb	22,453 Btu/lb
Electricity	3,414 Btu/kWh	3,414 Btu/kWh
Ethanol (E100)	76,330 Btu/gallon	84,530 Btu/gallon
Liquefied Natural Gas	51,585 Btu/gallon	84,820 Btu/gallon
Propane (LPG)	84,950 Btu/gallon	91,410 Btu/gallon
Methanol	57,250 Btu/gallon	65,200 Btu/gallon

Source: Fuel Properties Comparison Table. Alternative Fuels Data Center (http://www.afdc.energy.gov/fuels/fuel_properties.php)

3. Carbon Dioxide Emissions

Data for carbon dioxide emissions is calculated by converting gallons of fuel consumed each year by transit agency, as converted into British Thermal Units, to carbon dioxide equivalents using emissions factors for transportation fuels. Emissions factors for transportation fuels like diesel, gasoline, compressed natural gas, biodiesel, propane, electricity, and other transit fuel that were used are the coefficients that are also used in the Voluntary Reporting of Greenhouse Gases Program of the Energy Information Administration: http://www.eia.gov/oiaf/1605/coefficients.html. Table 3.3 presents the carbon dioxide emission factors for transportation fuels. The emission factor for electricity is based on conversion made from the Greenhouse Gas Equivalencies Calculator: http://www.epa.gov/cleanenergy/energy-resources/calculator.html. One kilowatt per hour of electricity is equivalent to 0.706 kilograms of carbon dioxide emissions.

Table 3.3: Carbon dioxide emission factors for transportation fuels

Transportation Fuel	Emission Factors	
	Kg CO2 per unit of volume	Kg CO2 per million Btu
Biodiesel (B100)	0.00 per gallon	0.00
Diesel Fuel (No. 1 and No. 2)	10.15 per gallon	73.15
Ethanol (E100)	0.00 per gallon	0.00
Methanol (M100)	4.11 per gallon	63.62
Motor Gasoline	8.91 per gallon	71.26
Jet Fuel, Kerosene	9.57 per gallon	70.88
Natural Gas	54.60 per Mcf	53.06
Propane	5.74 per gallon	63.07
Residual Fuel (No. 5 and No. 6 Fuel Oil)	11.79 per gallon	78.80

Source: Fuel Emission Coefficients. Voluntary Reporting of Greenhouse Gases Program (http://www.eia.gov/oiaf/1605/coefficients.html#tbl2)

4. Passenger Miles Traveled

Historical data from 2000 to 2011 for passenger miles traveled for each urban area is collected from the National Transit Database. Passenger miles traveled is measured as the cumulative sum of the distances ridden by each passenger.

5. Energy Intensity

Data for energy intensity is calculated by dividing energy consumption by passenger miles traveled. This reflects the level of energy consumed as input over the passenger miles traveled as output.

6. Carbon Dioxide Emissions Intensity

Data for carbon dioxide emissions intensity is calculated by dividing carbon dioxide emissions in the urban area by passenger miles traveled. This reflects the level of carbon dioxide that is emitted in the area as input over the passenger miles traveled as output.

7. Energy Consumption per Capita

Data for energy consumption per capita is calculated by dividing energy consumption over total population of the urban area.

8. Carbon Dioxide Emissions per Capita

Data for carbon dioxide emissions per capita is calculated by dividing carbon dioxide emissions in the urban area over total population of the urban area.

9. Population Estimates

Population data for each urban area is available for census years 2000 and 2010. Population estimates are calculated using a growth rate method, wherein growth increments are spread throughout the years from 2000 to 2011 using the population growth rate.

10. Land Area Estimates

Land area data for each urban area is available for census years 2000 and 2010. Land area estimates are calculated using a growth rate method, wherein growth increments are spread throughout the years from 2000 to 2011 using the population growth rate.

11. Housing Units Estimates

Housing units' data for each urban area is available for census years 2000 and 2010. Housing units' estimates are calculated using a growth rate method, wherein growth increments are spread throughout the years from 2000 to 2011 using the population growth rate.

12. Employment Establishments Estimates

Data for the total number of employment establishments is available from the County and Metropolitan Statistical Area Business Patterns database under the North

American Industry Classification System (NAICS). Data for years 2000 to 2010 was generated from the Censtats website: http://censtats.census.gov/cgi-bin/msanaic/msasect.pl) while data for 2011 is estimated, using data from 2010 levels, assuming that there are no changes in the number of establishments in the area from 2010 to 2011.

13. Population Density

Population density for each urban area is calculated by dividing the population of the urban area with the land area in square miles.

14. Housing Density

Housing density for each urban area is calculated by dividing the total number of housing units in the urban area with the land area in square miles.

15. Employment Establishment Density

Employment establishment density for each urban area is calculated by dividing the total number of employment establishment in the urban area with the land area in square miles.

16. Total Ridership

Historical data from 2000 to 2011 for ridership for each urban area is collected from the National Transit Database. This indicator is represented by unlinked passenger trips (UPT), which is defined as the number of passengers who board public transportation vehicles. Passengers are counted each time they board vehicles no matter how many vehicles they use to travel from their origin to their destination.

17. Total Directional Route Miles for Each Urban Area

Historical data from 2000 to 2011 for directional route miles for each urban area is collected from the National Transit Database. Directional route miles are the mileage in each direction over which public transportation vehicles travel while in revenue service. Directional route miles are a measure of the route path over a facility or roadway and are computed with regard to the direction of the service, but without regard to the number of traffic lanes or rail tracks existing in the right-of-way. The directional route miles do not include the staging or storage areas at the beginning or the end of a route.

18. Total Operating Expenses for Transit Modes

Historical data from 2000 to 2011 for operational expenses for each urban area is collected from the National Transit Database. The operating expenses are the expenses associated with the operation of the transit agency.

19. Total Vehicles Operated at Maximum Service

Historical data from 2000 to 2011 for the total vehicles operated at maximum service directional route miles for each urban area is collected from the National Transit Database. The vehicles operated at maximum service indicator are the number of revenue vehicles operated to meet the annual maximum service requirement. This is the revenue vehicle count during the peak season of the year, on the week day that maximum service is provided. Vehicles operated in maximum service exclude atypical days or one-time special events.

20. Light Rail Ridership

Historical data from 2000 to 2011 for the light rail transit ridership for each urban area is collected from the National Transit Database.

21. Light Rail Directional Route Miles for Each Urban Area

Historical data from 2000 to 2011 for the light rail transit directional route miles for each urban area is collected from the National Transit Database.

22. Light Rail Operating Expenses

Historical data from 2000 to 2011 for the light rail transit operating expenses for each urban area is collected from the National Transit Database.

23. Light Rail Vehicles Operated at Maximum Service

Historical data from 2000 to 2011 for the light rail passenger vehicles operated at maximum service is collected from the National Transit Database.

24. Light Rail Presence

Data for light rail presence included in the study is based on operating expenses data for transit modes from the National Transit Database. Data used in the analysis is converted to ordinal data, wherein the numbers 1 and 0 are used to indicate whether light rail is available in the urban area.

25. Commuter Rail Presence

Data for commuter rail presence included in the study is based on operating expenses data for transit modes from the National Transit Database. Data used in the analysis is converted to ordinal data, wherein the numbers 1 and 0 are used to indicate whether commuter rail is available in the urban area.

26. Heavy Rail Presence

Data for heavy rail presence included in the study is based on operating expenses data for transit modes from the National Transit Database. Data used in the analysis is converted to ordinal data, wherein the numbers 1 and 0 are used to indicate whether light rail is available in the urban area.

27. Bus System Presence

Data for bus system presence included in the study is based on operating expenses data for transit modes from the National Transit Database. Data used in the analysis is converted to ordinal data, wherein the numbers 1 and 0 are used to indicate whether bus systems rail is available in the urban area.

28. Light Rail Energy Consumption

Data for light rail energy consumption is calculated based on lower energy content for electricity multiplied by the number of kilowatt hours used for operating light rail services. The fuel conversion factor of the energy from electric propulsion is based on the energy content values in Table 3-2.

29. Light Rail Carbon Dioxide Emissions

Data for light rail carbon dioxide emissions is calculated based on the emission factor for electricity. The emission factor for electricity is based on conversion made from the Greenhouse Gas Equivalencies Calculator of the EPA: http://www.epa.gov/cleanenergy/energy-resources/calculator.html. One kilowatt per hour of electricity is equivalent to 0.706 kilograms of carbon dioxide emissions.

Chapter Summary

This chapter presented a detailed description of the method of analysis, the research design and the data used for conducting the statistical analysis, regression analysis and the technical analysis to address the research questions.

The results of the analysis will be presented in the succeeding chapter. A summary of the output tables will be presented for each round of regression analysis. Supporting tables and detailed regression outputs will be presented in the Appendices section of the study.

CHAPTER 4: PRESENTATION OF THE RESULTS OF ANALYSIS

The descriptive statistics for all variables used in the study as well as the significant bivariate regression results and results of the series of multiple regression analysis are presented in this chapter. Descriptive statistics on all variables used in this analysis are presented in the first section. The second section presents the significant bivariate regression results for all dependent variables and selected independent variables. The bivariate regression shows the general direction by which each variable affect the environmental sustainability indicators. The third section presents the results of the series of regression analysis to address each of the research questions. The regression analysis results are presented in two parts for each research question, and include the discussion of the results for each round of regressions. The regressions with the largest percentages of variances explained by independent variables will be used for an impact analysis for changes in light rail presence in urban areas and for changes in ridership. The results of the impact analysis are also presented in this chapter.

A summary of the regression analysis for both OLS and fixed effects approaches is presented in Appendix B. For each analysis result, key measures to consider are the R-square and the F-ratio. The R-square measures the proportion of the variation explained by the model. The model fits perfectly is the value of the R-square is equal to 1. An R-square closer to 0, on the other hand, indicates that the fit predicts that the model is no better than the overall response mean. In other words, the model with a lower R-square is not a good predictor model for environmental sustainability. The F-ratio, on the other hand, evaluates the effectiveness of the model, and is presented in the analysis of variance. If the probability associated with the F-ratio is small, then the model is considered a better statistical fit for the data used in the study. The observed significance probability (p-value) of 0.05 or less is often considered as evidence of a regression effect. In other words, estimates must have p-values less than 0.05 to be considered as significant estimates of factors for the model.

Descriptive Statistics

Table 4.1 presents the summary of the descriptive statistics for selected environmental sustainability indicators used in the analysis.

For selected environmental sustainability indicators, average air quality index for all data used in all urban areas is 41, which is within the range of 0-50, where air quality conditions are described as "good" (Table 3.1). Average energy intensity for all data for urban areas included in this study is 7,582 BTU per passenger mile, while average energy consumption per capita is 305,240 BTU. Average carbon dioxide emissions intensity is 0.52 kilograms of CO2 per passenger mile, while average CO2 emission per capita is 20 kilograms of CO2.

Average energy consumption for urban areas is 382.6 billion BTUs, while average CO2 emission for urban areas is 21.7 million kilograms of carbon dioxide. Average passenger miles traveled in urban areas is 144.3 million miles. On the average, population density is about 2,110 people per area square mile, while there are about 1,271 houses per area square mile. In urban areas, there are about 80 employment establishments per are square mile.

Table 4.1: Descriptive statistics for all variables used in the study

Variables (units of measurement)	Mean	Standard Deviation	Min	Maximum	N
Dependent Variables:					
Air quality index	41.05	12.87	4.00	132.00	4164
Energy Intensity (Btu/mile)	7582.23	20434.58	46.12	806680.48	3404
Carbon Dioxide Emission Intensity (kg/mile)	0.52	1.50	0.00	58.99	3336
Energy Consumption per capita (Btu)	305240.82	460346.81	758.78	21303934.60	3450
Carbon Dioxide Emission per capita (kg)	20.10	30.64	0.00	1557.64	3381
Independent Variables:					
Light Rail Transit (LRT) Presence (Yes=1; No=0)	0.05	0.22	0	1	5832
Commuter Rail Transit (CRT) Presence (Yes=1; No=0)	0.03	0.18	0	1	5832
Heavy Rail Transit (HRT) Presence (Yes=1; No=0)	0.02	0.15	0	1	5832
Motorized Bus (MB) Presence (Yes=1; No=0)	0.67	0.47	0	1	5832
Population Density (population/sq mile)	2110.79	873.84	583.55	8870.35	5828
Housing Density (housing units/sq mile)	1271.18	5696.10	12.00	186636.55	5823
Employment Density (emp establishments/sq mile)	80.28	41.09	9.38	469.84	4268
Ridership (in millions)	28.05	212.28	0.00	4159.85	4016
Directional Route Miles (mile)	733.57	1709.95	0.00	23402.90	3831
Total Operating Expenses (million US dollars)	83.94	551.45	0.00	11845.16	4035
Vehicles Operated at Maximum Service	287.00	1248.80	0.00	21899.00	4039
LRT Ridership (in millions)	16.10	17.47	0.03	80.28	291
LRT Directional Route Miles (mile)	49.67	35.81	1.30	152.40	290
LRT Operating Expenses (million US dollars)	42.97	39.92	0.10	174.70	291
LRT Vehicles Operated at Maximum Service	51.38	42.02	1.00	156.00	291
LRT Passenger Miles Traveled (million miles)	74.03	74.37	0.02	337.52	289
LRT Energy Consumption (million Btu)	84284.02	73793.29	3.28	332617.00	291
LRT Carbon Dioxide Emissions (million kg)	17.43	15.26	0.00	68.78	291
Other Variables:					
Energy Consumption (million Btu)	382636.99	1886880.00	96.47	31606700.00	3450
Carbon Dioxide (CO2) Emissions (million kg)	21.72	90.91	0.00	1439.89	3381

Table 4.1: (continued)

Variables (units of measurement)	Mean	Standard Deviation	Min	Maximum	N
Passenger Miles Traveled (million miles)	144.30	1164.85	0.02	22390.73	3901
Population	428488.89	1245892.97	5661.10	18406438.40	5828
Land Area (square miles)	165.83	315.20	3.81	3459.96	5828
Housing Units	175253.24	455633.30	3697.40	7986364.80	5827
Employment Establishments	16860.60	39272.87	801	541255.00	4268

Source: National Transit Database, Census, Energy Information Administration (EIA) Database, Alternative Fuels Data Center, Author Calculations

In terms of ridership, about 28 million commuters use public transit every year. About 16 million of total riders use light rail transit services on the average every year. Operating expenses for transit agencies average about $83 million, about half of which ($42 million) is spent for light rail transit in urban areas on the average. Average total directional route miles for transit is 733 miles, while average directional route miles specific to light rail is 49 miles. Average total vehicles operated at maximum service are 287 vehicles while average passenger vehicles for light rail that are operated at maximum service is 51 vehicles. Lastly, average light rail energy consumption reached 84 million Btu, while average light rail carbon dioxide emissions are 17 million kilograms for a year.

Bivariate Analysis Results

Bivariate analysis shows the relationship between one independent variable with one dependent variable. This analysis focuses on two continuous variables. The results of the bivariate regression indicate the individual relationships of each independent variable toward the selected indicators for environmental sustainability.

A summary of the results of the bivariate analysis is presented in Table 4-2. Based on the results, light rail presence is a significant determinant for all the selected environmental sustainability indicators, however, the models show low R-square values. The models for air quality index, energy per capita and CO2 emissions per capita, show 9 percent, 5 percent and 3 percent of the variance in light rail presence respectively. For energy intensity and CO2 intensity models, the R-square is less than one percent. This means that only less than 1 percent of the variance is explained. For all the models, the results indicate that the bivariate models for light rail presence and environmental sustainability indicators are not good models for predicting environmental sustainability in urban areas.

The bivariate analysis also indicates that the commuter rail presence, heavy rail presence, population density, and housing density are not good predictors of all five environmental sustainability indicators. Employment density, however, indicates that good predictability for energy per capita and CO2 per capita. About 10 percent of the variance in the models can be explained by employment density. The results also indicate that ridership has a significant relationship with energy per capita. About 20 percent of the variance can be explained in the model between ridership and energy per capita.

Directional route miles affect air quality index, energy per capita and CO2 per capita. R-square values are 12 percent, 33 percent and 19 percent respectively. The variance for energy per capital model has a larger R-square value, which means that there is a larger chance of a better bivariate fit. Operating expenses and vehicles operating at maximum service are also good predictors for energy per capita and CO2 per capita.

The light rail characteristics included in the models – ridership, directional service route miles, operating expenses, vehicles operated at maximum service, passenger miles traveled, energy consumption and CO2 emissions – are good predictors for energy intensity and CO2 intensity. R-square values range from 23 percent to 36 percent. However, the light rail characteristics are not good predictors for air quality, energy per capita and CO2 per capita, which have R-square values that are less than 10 percent. Figures that show the bivariate fit of the statistically significant models are presented in Appendix A.

Table 4.2: Bivariate analysis results for dependent and independent variables

Particulars	Air quality index	Energy Intensity	CO2 Intensity	Energy per Capita	CO2 Emissions per Capita
Light Rail Transit (LRT) Presence (Yes=1; No=0)	R-Square: 0.0903 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0038 Prob>F: 0.0003* Direction: Negative	R-Square: 0.0040 Prob>F: 0.0002* Direction: Negative	R-Square: 0.0507 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0269 Prob>F: <0.0001* Direction: Positive
Commuter Rail Transit (CRT) Presence (Yes=1; No=0)	R-Square: 0.036 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0007 Prob>F: 0.1192 Direction: Negative	R-Square: 0.0016 Prob>F: 0.0202* Direction: Negative	R-Square: 0.0759 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0367 Prob>F: <0.0001* Direction: Positive
Heavy Rail Transit (HRT) Presence (Yes=1; No=0)	R-Square: 0.0542 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0002 Prob>F: 0.3798 Direction: Negative	R-Square: 0.0009 Prob>F: 0.0745 Direction: Negative	R-Square: 0.0643 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0255 Prob>F: <0.0001* Direction: Positive

Table 4.2: (continued)

Particulars	Air quality index	Energy Intensity	CO2 Intensity	Energy per Capita	CO2 Emissions per Capita
Population Density (population/sq mile)	R-Square: 0.0406 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0052 Prob>F: <0.0001* Direction: Negative	R-Square: 0.0066 Prob>F: <0.0001* Direction: Negative	R-Square: 0.0590 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0309 Prob>F: <0.0001* Direction: Positive
Housing Density (housing units/sq mile)	R-Square: 0.0006 Prob>F: 0.1136 Direction: Positive	R-Square: 0.0000 Prob>F: 0.8138 Direction: Positive	R-Square: 0.0000 Prob>F: 0.7977 Direction: Positive	R-Square: 0.0002 Prob>F: 0.3876 Direction: Positive	R-Square: 0.0002 Prob>F: 0.3573 Direction: Positive
Employment Density (emp establishments/sq mile)	R-Square: 0.0000 Prob>F: 0.6628 Direction: Positive	R-Square: 0.0013 Prob>F: 0.0446* Direction: Negative	R-Square: 0.0016 Prob>F: 0.0254* Direction: Negative	R-Square: 0.1233 Prob>F: <0.0001* Direction: Positive	R-Square: 0.1014 Prob>F: <0.0001* Direction: Positive
Ridership (in millions)	R-Square: 0.0301 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0004 Prob>F: 0.1924 Direction: Negative	R-Square: 0.0008 Prob>F: 0.0982 Direction: Negative	R-Square: 0.2002 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0874 Prob>F: <0.0001* Direction: Positive
Directional Route Miles (mile)	R-Square: 0.1230 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0018 Prob>F: 0.0131* Direction: Negative	R-Square: 0.0031 Prob>F: 0.0015* Direction: Negative	R-Square: 0.3340 Prob>F: <0.0001* Direction: Positive	R-Square: 0.1944 Prob>F: <0.0001* Direction: Positive
Total Operating Expenses (million US dollars)	R-Square: 0.0316 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0005 Prob>F: 0.1609 Direction: Negative	R-Square: 0.0009 Prob>F: 0.0720 Direction: Negative	R-Square: 0.2274 Prob>F: <0.0001* Direction: Positive	R-Square: 0.1045 Prob>F: <0.0001* Direction: Positive
Vehicles Operated at Maximum Service	R-Square: 0.0576 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0012 Prob>F: 0.0417* Direction: Negative	R-Square: 0.0018 Prob>F: 0.0138* Direction: Negative	R-Square: 0.3033 Prob>F: <0.0001* Direction: Positive	R-Square: 0.1589 Prob>F: <0.0001* Direction: Positive

Table 4.2: (continued)

Particulars	Air quality index	Energy Intensity	CO2 Intensity	Energy per Capita	CO2 Emissions per Capita
LRT Ridership (in millions)	R-Square: 0.0036 Prob>F: 0.3151 Direction: Negative	R-Square: 0.2515 Prob>F: <0.0001* Direction: Negative	R-Square: 0.2600 Prob>F: <0.0001* Direction: Negative	R-Square: 0.1071 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0370 Prob>F: 0.0010* Direction: Positive
LRT Directional Route Miles (mile)	R-Square: 0.0147 Prob>F: 0.0425* Direction: Positive	R-Square: 0.3351 Prob>F: <0.0001* Direction: Negative	R-Square: 0.3670 Prob>F: <0.0001* Direction: Negative	R-Square: 0.0284 Prob>F: 0.0039* Direction: Positive	R-Square: 0.0001 Prob>F: 0.8386 Direction: Positive
LRT Operating Expenses (million US dollars)	R-Square: 0.0008 Prob>F: 0.6353 Direction: Negative	R-Square: 0.2654 Prob>F: <0.0001* Direction: Negative	R-Square: 0.2914 Prob>F: <0.0001* Direction: Negative	R-Square: 0.1349 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0360 Prob>F: 0.0011* Direction: Positive
LRT Vehicles Operated at Maximum Service	R-Square: 0.0004 Prob>F: 0.7140 Direction: Negative	R-Square: 0.3134 Prob>F: <0.0001* Direction: Negative	R-Square: 0.3298 Prob>F: <0.0001* Direction: Negative	R-Square: 0.1080 Prob>F: <0.0001* Direction: Positive	R-Square: 0.0306 Prob>F: 0.0027* Direction: Positive
LRT Passenger Miles Traveled (million miles)	R-Square: 0.0173 Prob>F: 0.0276* Direction: Positive	R-Square: 0.2331 Prob>F: <0.0001* Direction: Negative	R-Square: 0.2544 Prob>F: <0.0001* Direction: Negative	R-Square: 0.0177 Prob>F: 0.0234* Direction: Positive	R-Square: 0.0009 Prob>F: 0.6094 Direction: Positive
LRT Energy Consumption (million Btu)	R-Square: 0.0130 Prob>F: 0.0563 Direction: Positive	R-Square: 0.2238 Prob>F: <0.0001* Direction: Negative	R-Square: 0.2572 Prob>F: <0.0001* Direction: Negative	R-Square: 0.0215 Prob>F: 0.0122* Direction: Positive	R-Square: 0.0018 Prob>F: 0.4592 Direction: Positive
LRT Carbon Dioxide Emissions (million kg)	R-Square: 0.0130 Prob>F: 0.0563 Direction: Positive	R-Square: 0.2238 Prob>F: <0.0001* Direction: Negative	R-Square: 0.2572 Prob>F: <0.0001* Direction: Negative	R-Square: 0.0215 Prob>F: 0.0122* Direction: Positive	R-Square: 0.0018 Prob>F: 0.4592 Direction: Positive

Source: Author’s Calculations

Regression Analysis Results

The results of the regression analysis are presented in two parts to correspond with the research questions. The first part will address the first research question: “How does light rail presence affect environmental sustainability indicators in urban areas?” This section covers the regression analysis of selected environmental sustainability indicators for all urban areas with basic and expanded models (as referred in Equations 3.2 and 3.3). Key variable for consideration in the analysis is the significance of light rail presence. If light rail presence is significant, then light rail in urban areas affects the selected environmental sustainability indicator.

The second part will address the second research question: “For urban areas that have light rail systems, how do urban area and light rail transit characteristics affect environmental sustainability indicators?” This section covers the regression analysis of selected environmental sustainability indicators for urban areas with light rail, with basic and expanded models (as referred in Equations 3.4 and 3.5). Key variables for considerations are the factors that are significant (with probability ratio that is less than 0.05). These significant variables are possible determinants that can influence the selected environmental sustainability indicators.

For this section, the model with the best fit (with the highest R-square) among the three rounds of regression for basic and expanded models is discussed for each dependent variable. The summary tables for all three rounds of regression are presented in Appendix B.

Research Question #1: Regression Analysis for All Urban Areas with LRT

To respond to the first research question, the expanded model from the third round of regressions that used the dataset without the urban areas with the highest residuals is the best fit and has the highest R-square values. Table 4.3 presents the parameter estimates for the relationship between LRT and Air quality index.

Table 4.3: Parameter estimates for LRT presence and air quality index

Variables	OLS		Fixed Effects	
Constant	37.677	*	42.252	*
	(0.658)		(1.000)	
LRT Presence	7.183	*	6.992	*
	(1.097)		(1.080)	
CRT Presence	-3.234		-2.735	
	(2.035)		(2.003)	
HRT Presence	10.340	*	10.230	*
	(3.365)		(3.311)	
LRT*CRT	-7.268	*	-7.778	*
	(2.893)		(2.847)	
LRT*HRT	1.268		1.063	
	(4.810)		(4.733)	
CRT*HRT	-11.711	*	-12.997	*
	(4.426)		(4.357)	
LRT*CRT*HRT	3.204		4.593	
	(6.090)		(5.994)	
Population Density	2.03E-03	*	0.002	*
	(3.88E-04)		(3.82E-04)	
Housing Density	4.06E-04	*	5.10E-04	*
	(1.03E-04)		(1.02E-04)	
Employment Density	-4.99E-02	*	-5.96E-02	*
	(8.11E-03)		(8.06E-03)	
Ridership	-1.47E-09		-1.33E-08	
	(6.98E-09)		(6.97E-09)	
Directional Route Miles	4.11E-03	*	0.004	*
	(3.61E-04)		(3.56E-04)	
Operating Expenses	-5.94E-09	*	-6.34E-10	
	(2.95E-09)		(2.95E-09)	

Table 4.3: (continued)

Variables	OLS	Fixed Effects	
Vehicles at Max Service	-1.91E-04	-4.17E-04	
	(1.11E-03)	(1.09E-03)	
Years			
2001		-0.924	
		(1.072)	
2002		-2.349	*
		(1.074)	
2003		-3.048	*
		(1.040)	
2004		-4.503	*
		(1.039)	
2005		-3.060	*
		(1.037)	
2006		-4.363	*
		(1.041)	
2007		-3.375	*
		(1.038)	
2008		-5.262	*
		(1.041)	
2009		-8.005	*
		(1.035)	
2010		-6.548	*
		(1.035)	
2011		-6.228	*
		(1.059)	
R-square	0.225	0.252	
N	2983	2983	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

The results show that for air quality index, light rail presence is significant and shows positive relationship. This result implies that LRT presence increases air quality index values. Aside from LRT, heavy rail presence is also significant together with a combination of light rail and commuter rail in urban areas, and a combination of heavy rail and commuter rail in urban areas. Other significant values include population density, housing density, employment establishment density, and public transit directional route miles.

Table 4.4 presents the parameter estimates for the relationship between LRT and energy intensity. The results show that for energy intensity, light rail presence is not significant. The combination of heavy rail and commuter rail, and the combination of LRT, CRT and HRT in urban areas are significant and show positive relationship. Other significant values include population density, housing density, employment establishment density, and public transit directional route miles.

Table 4.4: Parameter estimates for LRT presence and energy intensity

Variables	OLS		Fixed Effects	
Constant	9667.907	*	9194.244	*
	(750.664)		(1153.070)	
LRT Presence	-1450.665		-1524.430	
	(1192.280)		(1190.825)	
CRT Presence	-3081.763		-2964.880	
	(2229.984)		(2225.563)	
HRT Presence	-4953.795		-4952.418	
	(3685.915)		(3677.306)	
LRT*CRT	5760.457		5758.913	
	(3169.571)		(3162.852)	
LRT*HRT	3899.155		3908.427	
	(5264.614)		(5252.296)	
CRT*HRT	23044.740	*	22899.620	*
	(4846.716)		(4837.017)	
LRT*CRT*HRT	-23047.130	*	-23009.380	*
	(6670.729)		(6656.872)	
Population Density	-1.349	*	-1.292	*
	(0.468)		(0.469)	
Housing Density	-0.085		-0.068	
	(0.120)		(0.121)	
Employment Density	10.084		7.856	
	(10.622)		(10.689)	

Table 4.4: (continued)

Variables	OLS		Fixed Effects	
Ridership	1.31E-05		1.20E-05	
	(7.65E-06)		(7.75E-06)	
Directional Route Miles	0.545		0.543	
	(0.394)		(0.394)	
Operating Expenses	3.03E-06		0.000	
	(3.24E-06)		(3.29E-06)	
Vehicles at Max Service	-4.503	*	-4.603	*
	(1.219)		(1.215)	
Years				
2001			-33.121	
			(1219.668)	
2002			570.572	
			(1226.605)	
2003			767.408	
			(1191.788)	
2004			3913.087	*
			(119.574)	
2005			1808.940	
			(1184.289)	
2006			59.748	
			(1181.154)	
2007			-383.077	
			(1175.834)	
2008			-529.288	
			(1175.696)	
2009			261.751	
			(1142.680)	
2010			359.844	
			(1142.386)	
2011			-281.811	
			(1181.369)	
R-square	0.028		0.030	
N	2946		2946	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table 4.5 presents the parameter estimates for the relationship between LRT and energy consumption per capita. The results show that light rail presence is significant and increases energy consumption per capita. The combination of light rail and commuter rail in urban areas is significant and show positive relationship. Other significant values include population density, housing density, employment establishment density, public transit ridership, public transit directional route miles, and public transit vehicles operating at maximum service.

Table 4.5: Parameter estimates for LRT presence and energy consumption per capita

Variables	OLS		Fixed Effects	
Constant	132961.200	*	132222.800	*
	(10809.460)		(16615.920)	
LRT Presence	38854.330	*	42452.380	*
	(17208.040)		(17169.090)	
CRT Presence	53722.810		50914.570	
	(32187.570)		(32091.150)	
HRT Presence	93992.970		94611.610	
	(53202.820)		(53024.190)	
LRT*CRT	120506.300	*	118870.800	*
	(45748.710)		(45604.850)	
LRT*HRT	46023.540		44179.800	
	(75991.190)		(75735.720)	
CRT*HRT	-60421.910		-55611.620	
	(69955.610)		(69745.090)	
LRT*CRT*HRT	-97810.330		-96942.670	
	(96286.370)		(95988.030)	
Population Density	26.332	*	23.705	*
	(6.745)		(6.742)	
Housing Density	5.951	*	5.194	*
	(1.738)		(1.742)	
Employment Density	821.157	*	907.495	*
	(152.658)		(153.465)	
Ridership	-0.001	*	-0.001	*
	(1.10E-04)		(1.12E-04)	

Table 4.5: (continued)

Variables	OLS		Fixed Effects	
Directional Route Miles	-11.801	*	-12.023	*
	(5.689)		(5.677)	
Operating Expenses	2.43E-05		0.000	
	(4.67E-05)		(4.74E-05)	
Vehicles at Max Service	206.337	*	208.347	*
	(17.560)		(17.511)	
Years				
2001			1322.548	
			(17566.830)	
2002			17334.950	
			(17666.060)	
2003			-9395.155	
			(17135.210)	
2004			-14593.260	
			(17062.320)	
2005			-20084.240	
			(16998.920)	
2006			-20402.500	
			(17016.290)	
2007			-18210.440	
			(16940.270)	
2008			-14781.390	
			(16952.970)	
2009			24853.450	
			(16476.780)	
2010			18785.750	
			(16472.420)	
2011			32120.240	
			(17034.410)	
R-square	0.452		0.458	
N	2972		2972	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table 4.6 presents the parameter estimates for the relationship between LRT and carbon dioxide emissions intensity. The results show that light rail presence is not significant. The combination of heavy rail and commuter rail, and the combination of LRT, CRT and HRT in urban areas are significant. Other significant values include population density and public transit vehicles operating at maximum service.

Table 4.6: Parameter estimates for LRT presence and CO2 intensity

Variables	OLS		Fixed Effects	
Constant	0.693	*	0.683	*
	(0.055)		(0.085)	
LRT Presence	-0.105		-0.113	
	(0.088)		(0.087)	
CRT Presence	-0.211		-0.197	
	(0.164)		(0.163)	
HRT Presence	-0.384		-0.384	
	(0.271)		(0.270)	
LRT*CRT	0.330		0.326	
	(0.233)		(0.232)	
LRT*HRT	0.290		0.289	
	(0.387)		(0.386)	
CRT*HRT	1.244	*	1.223	*
	(0.356)		(0.355)	
LRT*CRT*HRT	-1.183		-1.170	*
	(0.490)		(0.489)	
Population Density	-1.05E-04	*	-9.90E-05	*
	(3.46E-05)		(3.46E-05)	
Housing Density	-5.18E-06		-3.00E-06	
	(8.86E-06)		(8.88E-06)	
Employment Density	7.24E-04		4.69E-04	
	(0.001)		(7.90E-04)	
Ridership	7.29E-10		5.54E-10	
	(5.62E-10)		(5.69E-10)	
Directional Route Miles	1.61E-05		1.56E-05	
	(2.90E-05)		(2.89E-05)	
Operating Expenses	1.25E-10		2.16E-10	
	(2.38E-10)		(2.42E-10)	

Table 4.6: (continued)

Variables	OLS		Fixed Effects	
Vehicles at Max Service	-2.16E-04	*	-2.26E-04	*
	(8.94E-05)		(8.92E-05)	
Years				
2001			-0.005	
			(0.090)	
2002			0.033	
			(0.090)	
2003			0.052	
			(0.088)	
2004			-0.272	*
			(0.088)	
2005			0.117	
			(0.087)	
2006			-0.013	
			(0.087)	
2007			-0.051	
			(0.087)	
2008			-0.076	
			(0.087)	
2009			-0.025	
			(0.084)	
2010			-0.024	
			(0.084)	
2011			-0.063	
			(0.087)	
R-square	0.021		0.031	
N	2883		2883	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table 4.7 presents the parameter estimates for the relationship between LRT and carbon dioxide emissions per capita. The results show that light rail presence is not significant. Significant values include housing density, employment establishment density, public transit ridership and public transit vehicles operating at maximum service.

Table 4.7: Parameter estimates for LRT presence and CO_2 emissions per capita

Variables	OLS		Fixed Effects	
Constant	9.695		11.258	
	(0.788)		(1.207)	
LRT Presence	0.898		1.017	
	(1.248)		(1.246)	
CRT Presence	3.172		3.208	
	(2.334)		(2.329)	
HRT Presence	-1.574		-1.592	
	(3.858)		(3.847)	
LRT*CRT	4.855		4.532	
	(3.318)		(3.309)	
LRT*HRT	8.484		8.298	
	(5.511)		(5.495)	
CRT*HRT	-6.712		-6.949	
	(5.074)		(5.061)	
LRT*CRT*HRT	-6.642		-5.982	
	(6.983)		(6.964)	
Population Density	0.001		0.001	
	(4.91E-04)		(4.91E-04)	
Housing Density	4.61E-04	*	4.54E-04	*
	(1.26E-04)		(1.27E-04)	
Employment Density	0.065	*	6.60E-02	*
	(0.011)		(1.12E-02)	
Ridership	6.41E-08	*	-6.76E-08	*
	(8.01E-09)		(8.11E-09)	
Directional Route Miles	-2.98E-04		-3.22E-04	
	(4.13E-04)		(4.12E-04)	
Operating Expenses	-1.89E-09		-4.06E-10	
	(3.39E-09)		(3.44E-09)	
Vehicles at Max Service	0.015	*	0.015	*
	(0.001)		(0.001)	
Years				
2001			0.001	
			(1.274)	
2002			0.862	
			(1.282)	

Table 4.7: (continued)

Variables	OLS	Fixed Effects
2003		-1.039
		(1.244)
2004		-1.719
		(1.239)
2005		-2.509
		(1.238)
2006		-2.589
		(1.243)
2007		-3.043
		(1.241)
2008		-3.562
		(1.242)
2009		-0.830
		(1.203)
2010		-1.295
		(1.204)
2011		-0.206
		(1.246)
R-square	0.311	0.318
N	2909	2909

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

For the first research question, the regression analysis results show positive relationships between LRT presence and air quality index and energy consumption per capita in urban areas. The results also showed that LRT presence in urban areas is not significant and does not influence energy intensity, CO2 intensity and CO2 emissions per capita.

Research Question #2: Regression Analysis for Urban Areas

To respond to the second research question, the expanded model from the third round of regressions that used the dataset without the urban areas with the highest residuals is the best fit and has the highest R-square values. Table 4.8 presents the possible determinants of Air quality index.

Table 4.8: Determinants of air quality index

Variables	OLS		Fixed Effects	
Constant	52.433	*	66.254	*
	(2.744)		(4.085)	
LRT Ridership	-2.41E-07		-5.51E-07	*
	(1.82E-07)		(1.80E-07)	
LRT DR Miles	0.070		0.024	
	(0.065)		(0.062)	
LRT Operating Expenses	-7.22E-08		1.06E-07	
	(7.56E-08)		(7.78E-08)	
LRT Veh at Max Service	0.027		0.055	
	(0.065)		(0.062)	
LRT Pass Miles Traveled	2.59E-08		6.51E-08	
	(3.65E-08)		(3.53E-08)	
LRT Energy Consumption	3.65E-11		-1.38E-12	
	(4.18E-11)		(4.03E-11)	
Population Density	-4.51E-04		-9.53E-05	
	(0.002)		(1.62E-03)	
Housing Density	0.004		1.04E-04	
	(0.002)		(2.45E-03)	
Employment Density	-0.072		-1.16E-01	*
	(0.046)		(4.63E-02)	
Ridership	1.46E-08		5.67E-09	
	(9.54E-09)		(9.20E-09)	
Directional Route Miles	0.002	*	2.49E-03	*
	(5.89E-04)		(5.75E-04)	
Operating Expenses	-4.03E-09		-4.84E-10	
	(4.22E-09)		(4.06E-09)	

Table 4.8: (continued)

Variables	OLS	Fixed Effects	
Vehicles at Max Service	-0.002	-2.49E-03	
	(0.002)	(1.54E-03)	
Years			
2001		0.396	
		(3.409)	
2002		-3.650	
		(3.474)	
2003		-3.874	
		(3.471)	
2004		-6.506	
		(3.409)	
2005		-5.703	
		(3.458)	
2006		-7.562	*
		3.479	
2007		-9.537	*
		(3.519)	
2008		-12.076	*
		(3.541)	
2009		-14.633	*
		(3.592)	
2010		-15.222	*
		(3.712)	
2011		-15.588	*
		(3.967)	
R-square	0.295	0.392	
N	274	274	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

The regression analysis shows that possible determinants for air quality index include LRT ridership, employment establishment density, and public transit directional route miles. LRT ridership and employment establishment density appear to lower Air quality index in urban areas with LRT systems. Public transit directional route miles appear to minimally increase air quality index values in urban areas with LRT.

Table 4.9 presents the possible determinants of energy intensity. Possible determinants include LRT ridership, LRT directional route miles, LRT operating expenses, and LRT passenger miles traveled. The significant parameter estimates show that LRT ridership and LRT directional route miles minimally lowers energy intensity. LRT operating expenses and passenger miles traveled, in contrast, increases energy intensity.

Table 4.9: Determinants of energy intensity

Variables	OLS		Fixed Effects	
Constant	5585.807	*	5892.607	*
	(269.043)		(415.668)	
LRT Ridership	-5.47E-05	*	-5.97E-05	*
	(1.79E-05)		(1.87E-05)	
LRT DR Miles	-26.638	*	-27.390	*
	(6.343)		(6.449)	
LRT Operating Expenses	1.84E-05	*	2.15E-05	*
	(7.44E-06)		(8.09E-06)	
LRT Veh at Max Service	-2.911		-2.755	
	(6.385)		(6.460)	
LRT Pass Miles Traveled	7.92E-06	*	8.63E-06	*
	(3.59E-06)		(3.67E-06)	
LRT Energy Consumption	-4.92E-10		-1.01E-09	
	(4.11E-09)		(4.20E-09)	
Population Density	-0.121		-0.147	
	(0.162)		(0.168)	
Housing Density	-0.245		-0.329	
	(0.245)		(0.255)	
Employment Density	-1.081		-0.661	
	(4.548)		(4.819)	

Table 4.9: (continued)

Variables	OLS	Fixed Effects
Ridership	1.34E-07	2.38E-08
	(9.39E-07)	(9.58E-07)
Directional Route Miles	-0.089	-8.28E-02
	(0.058)	(5.98E-02)
Operating Expenses	8.03E-08	1.54E-07
	(4.15E-07)	(4.23E-07)
Vehicles at Max Service	-0.064	-8.74E-02
	(0.157)	(0.160)
Years		
2001		-142.459
		(350.479)
2002		195.447
		(357.314)
2003		-258.059
		(356.977)
2004		29.640
		(350.284)
2005		-194.902
		(355.172)
2006		-296.560
		(357.327)
2007		-266.535
		(361.249)
2008		-703.211
		(490.544)
2009		-368.166
		(288.950)
2010		-380.408
		(244.141)
2011		-407.569
R-square	0.455	0.474
N	275	275

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table 4.10 presents the possible determinants of energy consumption per capita. Possible determinants include LRT ridership and LRT passenger miles traveled. The results indicate that LRT ridership increases energy consumption per capita, while LRT passenger miles traveled minimally lowers energy consumption per capita. Other significant variables include population density, housing density, employment establishment density, public transit ridership and public transit vehicles operating at maximum service.

Table 4.10: Determinants of energy consumption per capita

Variables	OLS		Fixed Effects	
Constant	459720.600	*	623980.200	*
	(65377.050)		(96882.520)	
LRT Ridership	0.016	*	0.013	*
	(0.004)		(0.004)	
LRT DR Miles	-591.431		-401.034	
	(1541.341)		(1503.210)	
LRT Operating Expenses	-0.004	*	-0.003	
	(0.002)		(0.002)	
LRT Veh at Max Service	185.384		344.780	
	(1551.460)		(1505.682)	
LRT Pass Miles Traveled	-0.003	*	-0.003	*
	(0.001)		(0.001)	
LRT Energy Consumption	1.87E-06		1.34E-06	
	(1.00E-06)		(9.79E-07)	
Population Density	-56.172		-96.268	*
	(39.344)		(39.240)	
Housing Density	-183.161	*	-210.608	*
	(59.650)		(59.470)	
Employment Density	2437.503	*	3469.700	*
	(1105.229)		(1123.203)	
Ridership	-0.001	*	-0.001	*
	(2.28E-04)		(2.23E-04)	

Table 4.10: (continued)

Variables	OLS		Fixed Effects	
Directional Route Miles	2.824		-6.026	
	(14.070)		(13.946)	
Operating Expenses	-8.57E-06		-9.80E-06	
	(1.01E-04)		(9.86E-05)	
Vehicles at Max Service	278.462	*	278.019	*
	(38.125)		(37.385)	
Years				
2001			-16179.020	
			(81688.510)	
2002			97009.270	
			(83281.490)	
2003			-135468.100	
			(83203.040)	
2004			-177492.000	*
			(81643.070)	
2005			-212422.200	*
			(82782.420)	
2006			-215326.200	*
			(83284.600)	
2007			-210274.700	*
			(84198.830)	
2008			-243777.800	*
			(84654.310)	
2009			-130465.600	
			(85810.810)	
2010			-154516.700	
			(88664.160)	
2011			-93639.440	
			(94994.910)	
R-square	0.611		0.655	
N	275		275	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table 4.11 presents the possible determinants of carbon dioxide emissions intensity. Possible determinants include LRT ridership, LRT directional route miles, and

LRT passenger miles traveled. The results indicate that LRT ridership and LRT directional route miles minimally lowers CO2 intensity. In contrast, LRT passenger miles traveled minimally increases CO2 intensity.

Table 4.11: Determinants of CO2 intensity

Variables	OLS		Fixed Effects	
Constant	0.384	*	0.428	*
	(0.022)		(0.034)	
LRT Ridership	-4.09E-09	*	-5.00E-09	*
	(1.45E-09)		(1.51E-09)	
LRT DR Miles	-0.002	*	-0.003	*
	(0.001)		(0.001)	
LRT Operating Expenses	1.01E-09		1.55E-09	*
	(6.03E-10)		(6.53E-10)	
LRT Veh at Max Service	-8.42E-05		-3.52E-05	
	(0.001)		(0.001)	
LRT Pass Miles Traveled	6.95E-10	*	8.22E-10	*
	(2.91E-10)		(2.96E-10)	
LRT Energy Consumption	-3.25E-14		-1.30E-13	
	(3.34E-13)		(3.39E-13)	
Population Density	-2.50E-06		-2.25E-06	
	(1.31E-05)		(1.36E-05)	
Housing Density	-2.80E-05		-4.04E-05	
	(1.99E-05)		(2.06E-05)	
Employment Density	-1.13E-04		-2.16E-04	
	(3.69E-04)		(3.89E-04)	
Ridership	-1.27E-11		-4.10E-11	
	(7.61E-11)		(7.74E-11)	
Directional Route Miles	-6.53E-06		-6.16E-06	
	(4.69E-06)		(4.83E-06)	
Operating Expenses	1.59E-11		2.91E-11	
	(3.37E-11)		(3.42E-11)	
Vehicles at Max Service	-4.51E-06		-6.64E-06	
	(1.27E-05)		(1.29E-05)	
Years				
2001			-0.009	
			(0.028)	

Table 4.11: (continued)

Variables	OLS	Fixed Effects	
2002		0.013	
		(0.029)	
2003		-0.019	
		(0.029)	
2004		0.002	
		(0.028)	
2005		-0.018	
		(0.029)	
2006		-0.029	
		(0.029)	
2007		-0.028	
		(0.029)	
2008		-0.062	*
		(0.029)	
2009		-0.036	
		(0.030)	
2010		-0.045	
		(0.031)	
2011		-0.047	
R-square	0.454	0.477	
N	275	275	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table 4.12 presents the possible determinants of carbon dioxide emissions per capita. Possible determinants include housing density, employment establishment density, public transit ridership and public transit vehicles operating at maximum service. None of the LRT characteristics in the study dataset affect CO2 emissions per capita.

Table 4.12: Determinants of CO2 emissions per capita

Variables	OLS		Fixed Effects	
Constant	33.270	*	48.137	*
	(5.061)		(7.534)	
LRT Ridership	9.05E-07	*	6.37E-07	
	(3.36E-07)		(3.39E-07)	
LRT DR Miles	-0.112		-0.114	
	(0.119)		(0.117)	
LRT Operating Expenses	-3.40E-07	*	-1.70E-07	
	(1.40E-07)		(1.47E-07)	
LRT Veh at Max Service	-0.013		0.002	
	(0.120)		(0.117)	
LRT Pass Miles Traveled	-1.61E-07	*	-1.30E-07	
	(6.75E-08)		(6.64E-08)	
LRT Energy Consumption	1.32E-10		8.61E-11	
	(7.74E-11)		(7.62E-11)	
Population Density	-0.003		-0.005	
	(0.003)		(0.003)	
Housing Density	-0.013	*	-0.016	*
	(0.005)		(0.005)	
Employment Density	0.129		0.182	*
	(0.086)		(0.087)	
Ridership	-8.60E-08	*	-9.11E-08	*
	(1.77E-08)		(1.74E-08)	
Directional Route Miles	6.29E-04		8.35E-04	
	(0.001)		(0.001)	
Operating Expenses	3.08E-09		4.25E-09	
	(7.81E-09)		(7.67E-09)	
Vehicles at Max Service	0.018	*	1.77E-02	*
	(0.003)		(0.003)	
Years				
2001			-1.172	
			(6.353)	
2002			6.916	
			(6.477)	
2003			-9.547	
			(6.471)	
2004			-11.941	
			(6.349)	
2005			-15.970	*
			(6.438)	

Table 4.12: (continued)

Variables	OLS	Fixed Effects	
2006		-16.253	*
		(6.477)	
2007		-16.225	*
		(6.548)	
2008		-19.695	*
		(6.583)	
2009		-13.194	*
		(6.673)	
2010		-14.116	*
		(6.895)	
2011		-11.442	
		(7.388)	
R-square	0.429	0.487	
N	275	275	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

The second question deals with finding possible determinants of the selected environmental sustainability indicators. The series of regression analysis indicate that factors that influence environmental sustainability varies and depends on the outcome variables: air quality index, energy intensity, energy consumption per capita, CO2 intensity and CO2 emissions per capita. The most common variables in all the regression analyses combined that provide the most influence with the selected environmental sustainability indicators are light rail ridership, light rail passenger miles traveled, light rail operating expenses, and light rail directional route miles.

Impact Analysis Results

The models with the highest variances explained by the independent variables are the expanded models from the regression analysis without the urban areas with highest residuals. Using these models for addressing the research questions, the actual values and the predicted values of the selected environmental sustainability indicators are compared with respect to the following changes in variables: 1) change in the number of urban areas with light rail presence based on size of the urban areas; and 2) change in level of light rail ridership. The classification for the size of the urban areas is based on the urban area classification used by the National Transit Database, as follows:

a) small size urban areas – urban areas with population less than 200,000;
b) medium size urban areas – urban areas with population greater than 200,000; and
c) large size urban areas – urban areas with population greater than 1 million.

For changes in light rail transit ridership, a 25 percent, 50 percent, 75 percent and 100 percent increase from the actual light rail ridership is assumed. The average actual and the average predicted values for each selected environmental sustainability indicators are compared with the average predicted values for changes in light rail presence in urban areas and light rail ridership.

Table 4.13 presents the impact analysis summary for changes in light rail presence in urban areas.

Table 4.13: Impact analysis on changes in light rail presence in urban areas

Particulars	Air Pollution	Energy Consumption		Greenhouse Gas Emissions	
	Air quality index	Energy Intensity	Energy per Capita	CO2 Intensity	CO2 per Capita
Average Actual Value	39.24	7261.95	308424.21	0.47	19.38
Average Predicted Value	46.77	5644.96	270599.63	0.44	46.94
Average Predicted Value for Change in LRT Presence in UZA groups:					
1. Small Size UZAs (Popn<200,000)	51.21	5644.96	297550.96	0.44	46.94
2. Medium Size UZAs (Popn >200,000)	44.25	5644.96	283300.39	0.44	46.94
3. Large Size UZAs (Popn >1 million)	46.97	5501.75	273171.71	0.43	46.94
4. Medium and Large Size UZAs	48.83	5501.75	285872.22	0.43	46.94
Change Impacts:					
Average Actual vs Average Predicted Value	7.53	-1616.99	-37824.58	-0.04	27.56
Average Predicted Values vs Change in LRT Presence in UZA groups					
1. Small Size UZAs (Popn<200,000)	4.44	0.00	26951.33	0.00	0.00
2. Medium Size UZAs (Popn >200,000)	-2.51	0.00	12700.75	0.00	0.00
3. Large Size UZAs (Popn >1 million)	0.20	-143.21	2572.07	-0.01	0.00
4. Medium and Large Size UZAs	2.06	-143.21	15272.59	-0.01	0.00

Source: Author Calculations Based on Expanded Models for All Urban Areas and Urban Areas with LRT Using Dataset without UZAs with Large Residuals;
Note: UZA classification based on classification used in the National Transit Database tables.
Changes in LRT ridership are assumed.

For air quality index, the average predicted value is larger than the average actual levels for all urban areas. As light rail is present in all small areas, air quality index increases by 4 points from the average predicted values. Furthermore, air quality index also decreases for medium size urban areas by 2 points from the average predicted values. For large urban areas, light rail presence minimally increases the predicted value for air quality index by 0.2 points. A combination of light rail presence in medium and large urban areas increases the predicted value for air quality index by 2 points.

For energy intensity, the average predicted value is lower than the average actual levels for energy intensity in all urban areas. When light rail is present in all small urban areas, the results indicate that there are no changes in the predicted values for energy intensity. The same result is projected when light rail is present in medium size urban areas. For large size urban areas and for the combination of medium size and large size urban areas that have light rail presence, the average actual predicted values decreased.

For energy consumption per capita, the average predicted value is also lower than the average actual values for energy consumption per capita. When light rail is present is small urban areas, there is no change from the predicted values. For medium size and large size urban areas, average predicted values increased by 907 points. Similarly, when light rail is present in all medium and large size urban areas, average predicted values for energy consumption per capita also increased.

For CO2 intensity, the average predicted value is lower by 0.4 points than the average actual values for CO2 intensity in all urban areas. When light rail is present in small and medium areas, there are no changes in the predicted values. However, as light rail is present in large size urban areas and in both medium and large size areas, CO2 intensity decreases by 0.1 points.

For CO2 emissions per capita, the average predicted value is lower than the actual values for CO2 emissions per capita by 3.75 points. However, regardless of whether light rail is present in any of the urban area groupings, there are no changes in the average actual predicted values for CO2 emissions per capita.

The results of the impact analysis indicates that for air quality index, more light rail in large urban areas have lower positive effect. For energy intensity, the results indicate that additional light rail in large urban areas, and in medium and large urban areas combined, decreases energy intensity. For energy consumption per capita, additional light rail in medium and large urban areas increases energy consumption. For CO2 intensity and CO2 emissions per capita, light rail presence has minimal negative effect in all urban area groupings.

Table 4.14 presents the impact analysis summary for changes in light rail ridership in urban areas.

Table 4.14: Impact analysis on changes in light ridership in urban areas

Particulars	Air Pollution	Energy Consumption		Greenhouse Gas Emissions	
	Air quality index	Energy Intensity	Energy per Capita	CO2 Intensity	CO2 per Capita
Average Actual Value	39.24	7261.95	308424.21	0.47	19.38
Average Predicted Value	60.33	5859.39	327636.48	0.42	35.30
Average Predicted Value for Change in LRT Ridership					
1. 25% Increase in LRT Ridership	60.26	5847.66	329994.48	0.42	35.30
2. 50% Increase in LRT Ridership	60.15	5835.92	332352.48	0.42	35.30
3. 75% Increase in LRT Ridership	60.04	5824.19	334710.47	0.42	35.30
4. 100% Increase in LRT Ridership	59.93	5812.46	337068.47	0.42	35.30
<u>Change Impacts:</u>					
Average Actual vs Average Predicted Value	21.09	-1402.57	19212.27	-0.05	15.92
Average Predicted Value for Change in LRT Ridership					
1. 25% Increase in LRT Ridership	-0.07	-11.73	2358.00	0.00	0.00
2. 50% Increase in LRT Ridership	-0.18	-23.46	4716.00	0.00	0.00
3. 75% Increase in LRT Ridership	-0.28	-35.19	7073.99	0.00	0.00
4. 100% Increase in LRT Ridership	-0.39	-46.92	9431.99	0.00	0.00

Source: Author Calculations Based on Expanded Models for All Urban Areas and Urban Areas with LRT Using Dataset without UZAs with Large Residuals;
Note: UZA classification based on classification used in the National Transit Database tables.
Changes in LRT ridership are assumed.

For air quality index, the average predicted value is larger than the actual values for air quality index in urban areas. A 25 percent increase in LRT ridership lowers the predicted air quality index values in urban areas by less than 1 point. As LRT ridership increases to 50 percent, 75 percent and 100 percent than the actual LRT ridership in the dataset, reduction in the levels for predicted air quality index increases, although very minimal and less than 1 point.

For energy intensity, average predicted value is lower than the average actual value for all urban areas. A 25 percent increase in LRT ridership lowers the average predicted value for energy intensity by 11 points. As LRT ridership increases to 50 percent, 75 percent and 100 percent, average predicted values decreases by larger margins, from 23 points, 35 points and 46 points, respectively.

For energy consumption per capita, average predicted value is larger than the average actual value for energy consumption per capita. A 25 percent increase in LRT ridership increases the average predicted value by 2358 points. As LRT ridership increases to 50 percent, 75 percent and 100 percent, average predicted values decreases by larger margins, from 4716 points, 7073 points and 9431 points, respectively.

For CO2 intensity, average actual predicted value is lower by 0.05 points than the actual value. The results indicate that there are no changes in predicted values regardless of changes in LRT ridership.

For CO2 emissions per capita, average actual predicted value is higher than the average actual value by 15.92 points. The results also indicate that there are no changes in predicted values regardless of changes in LRT ridership.

The results of the impact analysis on changes in LRT ridership indicates that an increase in LRT riders lowers air quality index and lowers energy intensity. For energy consumption per capita, increase in LRT ridership increases the predicted values. More LRT riders will increase the level of energy consumption in the urban area.

Chapter Summary

The results of the bivariate regressions and the series of multiple regression analysis for this study indicate the light rail presence affects the selected environmental sustainability indicators at varying degrees. In terms of identifying the possible determinants of the selected environmental sustainability indicators, urban area characteristics, light rail characteristics and public transit characteristics affect selected environmental sustainability indicators at varying degrees. The results of the impact analysis, however, indicate that light rail presence has significant effects on minimizing air pollution and energy consumption. The effect of light rail presence on minimizing greenhouse gas emissions is not significant. In terms of light rail ridership, the impact analysis results imply that more light rail riders lowers air quality index levels (although minimally) and that more light rail riders lowers energy intensity. The results also imply that increases in LRT ridership do not significantly affect minimizing energy consumption per capita and minimizing greenhouse gas emissions.

The next chapter will provide a discussion of the results and the implications of these results to environmental policy, energy policy, and transportation policy. The next chapter will also discuss how the results validated the initial hypotheses previously outlined in the study.

CHAPTER 5: DISCUSSION OF RESULTS

This chapter provides a discussion of the results of the analysis and its implications to environmental policy, energy policy, transportation policy, and sustainable transportation. To begin this discussion, a summary of the results of the analysis is presented in the context of testing and validating the hypotheses that were previously outlined. The discussions seek to enrich the analysis of the results and connect the findings to policy implications.

The research questions for this study are expressed as follows:

1. How does light rail presence affect environmental sustainability indicators in urban areas?
2. For urban areas that have light rail systems, how do light rail, public transit, and urban area characteristics affect environmental sustainability indicators?

General findings of the study indicate that light rail presence affect the selected environmental sustainability indicators in urban areas at varying degrees. Based on the analyses of variances, the best models for analysis among the series of regressions conducted are the third round regression results that yielded the highest R-square values. Using the third round regression results – with the dataset without the urban areas that have the highest residuals, light rail presence is a significant variable for all five environmental sustainability indicators under the basic model. As additional variables are included in the analysis to control for effects of urban area and public transit characteristics, light rail presence is only significant for air quality index, but various combinations with other forms of passenger rail help maintain its significance for energy intensity, energy consumption per capita and CO2 intensity. Light rail presence is not significant for CO2 emissions per capita.

In determining possible determinants of environmental sustainability among urban areas with light rail, the third round of regression results indicate the best model fits to understand influential factors. Significant variables also vary per environmental sustainability indicator. The most common indicators for all five models are housing density, light rail ridership, light rail directional route miles, light rail operating expenses, total public transit ridership and total number of vehicles operating at maximum service. LRT ridership and total public transit directional route miles affect the air quality index, while LRT ridership, LRT directional route miles and LRT operating expenses affect energy intensity. Housing density, employment density, total public transit ridership and total number of vehicles operating at maximum service affect energy consumption per capita. LRT directional route miles, LRT operating expenses, LRT passenger miles traveled and housing density affect CO2 intensity. Finally, housing density, total public transit ridership and the total number of vehicles operating at maximum service affect CO2 emissions per capita.

The directions and strength of the relationship among these variables with the selected environmental sustainability indicators will be discussed in the context of testing and validating the hypotheses that were previously outlined in the study. Using the third round regression results, the significant variables for each model are highlighted.

Validating the Hypotheses

The results of the analysis are discussed to test and validate each of the following hypotheses:

1. Light rail presence in urban areas has a significant influence on minimizing air pollution, energy use and greenhouse gas emissions.

Light rail presence in urban areas has a significant influence on minimizing air pollution, and provides significant influence over minimizing energy use and minimizing greenhouse gas emissions through a combination of other forms of passenger rail in urban areas.

Light rail presence increases the air quality index values. Heavy rail presence also increases the air quality index values. The combination of light rail and commuter rail presence and heavy rail and commuter rail presence both lower air quality index values. Higher population density and housing density increases air quality index values, while higher employment establishment density lowers the air quality index values. An increase in total public transit directional route miles also increases air quality index.

Light rail presence does not provide significant effects for energy consumption indicators, but combined with other forms of passenger rail, light rail presence provides some significant effects. The combination of light rail, heavy rail and commuter rail in urban areas lowers energy intensity. In contrast, the combination of heavy rail and commuter rail increases energy intensity. An increase in population density and the number of vehicles operating at maximum service for public transit lowers energy intensity. For energy per capita, a combination of light rail and commuter rail presence increases energy consumption per capita. Higher population density, housing density and employment establishment density in urban areas also increases energy consumption per capita. An increase in the number of vehicles operated at maximum service also increases energy per capita. However, an increase in total public transit ridership and total directional route miles for public transit lowers energy per capita. This may be due to the spreading out of energy consumption to all members of the population.

For minimizing greenhouse gas emissions, light rail presence is not a significant factor in understanding CO2 intensity and CO2 emissions per capita. However, the combination of light rail, heavy rail and commuter rail presence in urban areas lowers CO2 intensity. In contrast, however, the combination of heavy rail presence and commuter rail presence increases CO2 intensity. This may be due to the larger traffic volumes carried by both heavy rail and commuter rail modes. The number of vehicles operating at maximum service also lowers CO2 intensity, although with minimal effect. Population density, housing density and employment establishment density also provide minimal positive effects on CO2 emissions per capita. Public transit ridership, on the other hand, provides minimal negative effect for CO2 emissions per capita.

In sum, light rail presence has a more significant influence over air quality index than all the other selected environmental sustainability indicators for energy consumption and greenhouse gas emissions. However, a combination of light rail presence with other modes in urban areas makes light rail significant for affecting energy consumption and greenhouse gas emissions.

2. Light rail characteristics affect environmental sustainability goals.

A number of light rail characteristics affect environmental sustainability goals. An increase in light rail ridership both lowers air quality index values and energy intensity. An increase in light rail directional route miles lowers energy intensity, but increases CO2 intensity. An increase in light rail operating expenses both minimally increases energy intensity and CO2 intensity. Finally, an increase in light rail passenger miles traveled also minimally increases CO2 intensity.

3. Public transit characteristics affect environmental sustainability goals.

Three public transit characteristics affect environmental sustainability goals. An increase in public transit ridership lowers energy per capita and CO2 per capita. An increase in directional route miles increases air quality index, while vehicles operated at maximum service increases energy per capita and CO2 per capita.

4. Urban densities affect environmental sustainability goals.

Among the three urban densities described in this study (population, housing and employment establishment density), only housing and employment establishment density show significant effects. Housing density affects energy consumption per capita, CO2 intensity and CO2 emissions per capita. An increase in housing density lowers energy per capita, CO2 intensity and CO2 emissions per capita. Employment establishment density, in contrast, increases energy consumption per capita. The more employment establishments in the urban area, the more energy is consumed.

Policy Implications

The primary contribution of this study is to provide empirical evidence on the influence of light rail presence on environmental sustainability in urban areas. Results showed that indeed, light rail presence influences the selected environmental sustainability indicators at varying degrees. Light rail presence, as it appears in the results of the analysis, has more influence on air quality index values than all the other selected environmental sustainability indicators.

Based on the results, it appears that light rail presence increases the air quality index. Contrary to the notion that light rail is environmentally sustainable and that light rail minimizes air pollution, it appears that light rail does not help improve air quality in the area. However, taking into consideration that air quality is only one aspect of environmental sustainability, this study cannot make any conclusions on the environmental sustainability of light rail transit based one aspect alone. The results also indicate that an increase in light rail presence can also lower energy intensity. In this case, the result indicates that light rail presence lowers the amount of energy consumed to achieve travel output (passenger miles traveled). The goal of the study to determine the influence of light rail on selected environmental sustainability is achieved through empirical evidence, but the result may not be necessarily conclusive as expected.

While the results focuses on light rail presence as main determinant for selected environmental sustainability indicators, the influence of heavy rail and the combination of light rail and other forms of transit in urban areas should also be considered as significant. Similar to the results with light rail presence, heavy rail presence also contributes to increases in air quality index values in the area.

Aside from enhancing the current literature on the environmental sustainability of light rail systems, the results of the analysis identified factors that influence environmental sustainability. By identifying influential factors, policy can be directed towards improving these factors so that the benefit of environmental sustainability is achieved. Noting that light rail ridership influences the selected environmental sustainability indicators, policy may be directed towards increasing light rail ridership in urban areas. The results of analysis can be used to aid policy formulation and analysis through more discussions on the significant factors that influence environmental sustainability.

The policy implications of the results of the analysis in this study are more relevant to the policy discussions on environmental policy, energy policy and transportation policy. Since this study is also done in the context of sustainability, the results also provide some insights on how the environmental sustainability goals of sustainable transportation area achieved.

For environmental policy, the findings of this study add to the discussion on the benefits and effects of light rail presence to air pollution and the use of energy resources. The government's environmental policy, typically established by the EPA, has focused traditionally on conservation of natural resources, but in the 1960's, policy focus on environment covered concerns over public health, which includes controlling air and water pollution, and limiting exposure to toxic chemicals (Kraft & Furlong, 2010). The findings of this study show that light rail increases air pollution, along with other forms of rail transit, in urban areas. However, since air pollution is only one aspect related to environmental sustainability, this study cannot conclude that light rail presence causes air pollution. There are many more factors that can be considered to boost this analysis, as well as methods that can specifically address providing causality for environmental sustainability goals.

Another aspect within environmental policy is climate change. The goal of climate change policy is to reduce the rate and mitigate the risks of climate change for future generations. This relates to lessening the use of fossil fuels, which leads to less CO2 emissions. Does LRT presence reduce CO2 emissions in urban areas? The results of the analysis using the existing data indicate the LRT presence is not significant for minimizing greenhouse gas emissions. With regards to air quality, the results of the analysis indicate that LRT increases the air quality index values, but the relationship cannot be causal, since there are many other omitted variables in the study that may provide a better insight on the relationship between LRT and air quality.

Another finding of this study is the effect of light rail presence on energy intensity and energy consumption per capita. While energy intensity and energy consumption per capita is measured at the urban area level, light rail presence effects are miniscule compared to all possible effects of other factors that contribute to energy consumption. These other factors may come from other sectors of society, and not only from the transportation sector. The same could also be said for CO2 intensity and CO2 emissions. The impact of light rail presence may be too miniscule or virtually absent on the selected environmental sustainability indicators because of there a many other unknown contributing factors that are also not included in the study. Hence, to relate the findings to overall environmental policy, focus must be on the value of the empirical findings on improving the discussion on the impact of light rail presence on the selected environmental sustainability goals, rather than focusing on concluding that light rail presence causes air pollution, energy consumption or greenhouse gas emissions. To provide causality, a different modeling approach is needed, and may be a subject for future study on this topic.

Environmental policy is also connected with energy policy, as energy sources contribute to harmful emissions to the environment that affect the population. Environmental policy also covers energy policy, especially with the enactment of the Energy Policy Act of 2005 (PL 109-58) and subsequent related energy policies such as the Energy Independence and Security Act of 2009 (PL 110-140) and with the funding of energy policy in the American Recovery and Reinvestment Act of 2009 (PL 111-5) (Kraft & Furlong, 2010). The findings of this study also reinforce the discussion for energy resource use, especially on how light rail presence affects energy consumption. Light rail presence is supposed to lower energy intensity, but the variable in the model is not significant. A different modeling approach in a future study may provide a more definitive conclusion on the impact of light rail presence on energy consumption.

Aside from the notion that energy policy is a natural resource policy component of environmental policy, the other policy component of energy policy covers environmental protection. Given that light rail operates on electricity as fuel, less CO_2 is emitted in the atmosphere. The policy decisions involving the use of alternative fuel vehicles and alternative fuel for public transit depends on government's motivations and commitment to protect the environment and lessen the effects of greenhouse gas emissions. The findings of this study indirectly reinforces the argument that rail in general has environmental protection benefits, if this analysis is interpreted based on the benefits of the use of electricity as fuel in transportation instead of petroleum based fuels that have more CO_2 emissions. However, careful consideration must be included when making generalizations regarding the possible benefits of the use of electricity as source of energy. Electricity is also coal-powered, which is also a form of fossil fuel. In addition, the waste generated for producing and renewing electricity may not be evident in areas that have LRT, but it is a possibility that the waste will be released in another part of the urban area, which may also be in an area away from the most populous, most congested and most dense parts of the urban area.

The findings also relate to implications on transportation policy. Transportation policy covers modal selection for public transit, and investments on public transit over other transportation investments on infrastructure such as highways, roads and bridges. Are there investments being made in providing sustainable public transit options? The findings of this study indicate that more operating expenses on light rail transit minimally increases energy intensity and CO2 intensity, but does not necessary cause energy intensity and CO2 intensity. A comparison of energy intensity and CO2 intensity as well as how energy consumption and CO2 emissions relate to ridership may provide additional insights than the findings from the regression analysis.

Table 5.1 presents a comparative analysis of light rail, heavy rail, commuter rail, and bus systems on energy intensity, CO2 intensity, energy consumption per public transit ridership and CO2 emissions per public transit ridership. Using 2011 data from the dataset used in the study and figures from the National Transit Database, the results show that of all four public transit systems compared, light rail does not have the lowest energy intensity, lowest CO2 intensity, lowest CO2 emissions per ridership and lowest CO2 emissions per ridership. Based on the comparative analysis, heavy rail has the least energy intensity, CO_2 intensity, energy consumption per ridership, and CO_2 emissions per ridership compared to light rail, commuter rail and bus systems.

Table 5.1: Comparative modal analysis for energy consumption and CO_2 emissions

Particulars	LRT	HRT	CRT	Bus
Energy Intensity (Btu/mile)	976.86	759.79	1,584.69	3,759.17
CO2 Intensity (kg/mile)	0.20	0.16	0.19	0.24
Energy per Ridership	5,848.65	3,607.50	38,868.68	14,651.76
CO2 per Ridership (kg)	1.21	0.75	4.61	0.93

Source: Author Calculations

Changes on light rail ridership, however, can improve the standing of light rail on energy intensity, CO_2 intensity, energy consumption per ridership and CO_2 emissions per ridership. Assuming that light rail ridership increases, from 25 percent to 100 percent, light rail appear to contribute less to energy intensity, CO_2 intensity, energy consumption per ridership and CO_2 emissions per ridership. Table 5.2 presents the comparative modal analysis of energy consumption and CO_2 emission when light rail ridership increases. The results indicate that light rail is the least energy intensive passenger rail mode, has less CO_2 intensity, less energy consumption per ridership and has less CO_2 emissions per ridership when light rail ridership increases by at least 63 percent. Compared to other modes, light rail has less energy and CO_2 impacts when light rail ridership increases by 63 percent. The results however, indicate that the larger passenger load brought by light rail on energy consumption and CO_2 emissions becomes smaller. At some point, increases in light rail ridership will reach a saturation point, wherein, increases in light rail ridership will not have any impact compared to the other modes. This finding can be a useful consideration when comparing and selecting public transit modes for transportation investments. This finding can be part of a benefit-cost analysis of choosing between light rail and another type of rail transit or in selecting to improve and increase existing bus systems in urban areas.

Table 5.2: Change impacts for increase in LRT ridership

Particulars	LRT	HRT	CRT	Bus
Energy per Ridership at 25% LRT Ridership Increase	5,706	3,607	38,869	14,652
Energy per Ridership at 50% LRT Ridership Increase	3,899	3,607	38,869	14,652
Energy per Ridership at 63% LRT Ridership Increase	3,588	3,607	38,869	14,652
Energy per Ridership at 70% LRT Ridership Increase	3,342	3,607	38,869	14,652
Energy per Ridership at 100% LRT Ridership Increase	2,924	3,607	38,869	14,652
CO2 per Ridership at 25% LRT Ridership Increase	1.18	0.75	4.61	0.93
CO2 per Ridership at 50% LRT Ridership Increase	0.81	0.75	4.61	0.93
CO2 per Ridership at 63% LRT Ridership Increase	0.74	0.75	4.61	0.93
CO2 per Ridership at 70% LRT Ridership Increase	0.69	0.75	4.61	0.93
CO2 per Ridership at 100% LRT Ridership Increase	0.60	0.75	4.61	0.93

Source: Author Calculations

Environmental policy, energy policy and transportation policy is integrated with the comprehensive agenda of sustainability at all levels of government. Hence, the role of public policy remains influential in shaping the macroeconomic, social and environmental aspects of society. While this study only focused on environmental sustainability, the study demonstrated how light rail presence affects environmental sustainability even through a selected number of indicators for environmental sustainability goals. Further research on this subject is encouraged, in addition to additional study on understanding light rail and its impacts on social and economic sustainability. The subject of improving this research and suggestions for policy recommendations are discussed in the concluding chapter for this study.

CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the summary, conclusions and recommendations of this study on environmental sustainability of light rail systems in urban areas. Suggestions for further improving this research are also outlined in this chapter.

Summary

The objective of this dissertation is to understand how light rail presence affects environmental sustainability in urban areas. For urban areas with existing light rail systems, this study also seeks to determine how light rail, urban area and public transit characteristics affect environmental sustainability. Environmental sustainability indicators were selected based on the environmental sustainability goals of minimizing air pollution, energy resource use and greenhouse gas emissions. Environmental sustainability goals were measured as air quality index, energy intensity, energy consumption per capita, carbon dioxide emissions intensity, and carbon dioxide emissions per capita as outcome variables. Using urban area and public transit data from 2000 to 2011, the impacts of light rail presence and other forms of passenger rail transit on selected environmental sustainability indicators were estimated through bivariate regression analysis and a series of multiple regressions with light rail, urban area and public transit characteristics. Findings indicate that light rail presence affects environmental sustainability in varying degrees for each of the outcome variables. Light rail presence increases the predicted values for air quality index, but does not significantly affect energy intensity, energy per capita, CO_2 intensity and CO_2 per capita. Possible determinants of the selected environmental sustainability indicators include light rail ridership, light rail directional route miles, light rail operating expenses, and light rail passenger miles traveled. Housing density and employment density also significantly affects environmental sustainability indicators. Public transit ridership, directional route miles, and the number of vehicles operating at maximum service also affect environmental sustainability. Further research on light rail presence is encouraged to improve the results of the analysis of environmental sustainability in urban areas.

Conclusions

Light rail presence affects environmental sustainability at varying degrees, depending on the approach of the analysis and the environmental sustainability measures used. The bivariate regression results established individual independent variable effects for each of the selected environmental sustainability indicators in the study. The results of the regression analyses, however, demonstrate a more refined representation of the effects of light rail presence and other significant variables on environmental sustainability indicators. While regression analysis results provide significant effects between the explanatory variables and the outcome variables, the results are not interpreted as causal effects. Light rail presence increases air quality index values but this study does not conclude that light rail causes air pollution to increase. While light rail presence does not have significant relationships with energy intensity, energy consumption per capita, CO_2 emissions intensity and CO_2 emissions per capita, this study also does not conclude that light rail presence can neither increase nor decrease the selected environmental sustainability indicators. This study establishes the relationships and the direction of these relationships between light rail presence and environmental sustainability in urban areas in the United States.

Given the results of the analysis, the main point of the study on the environmental sustainability of light rail transit is to establish the fact that light rail presence is not sufficient to encourage sustainability in urban areas. Making the light rail transit available in urban areas is not the primary driving factor that makes it sustainability. One of the findings of this study indicates that LRT ridership can be the driving factor that can make LRT systems sustainable. People should be able to utilize LRT when available to provide an impact. If LRT is available and less people ride the LRT systems, and more people prefer to ride privately owned vehicles instead of public transit, then LRT does not appear to be sustainable. LRT ridership is the key to influence environmental sustainability in urban areas.

Policy Recommendations

A key policy recommendation arising from the realization that LRT ridership may provide the key to influence environmental sustainability is to focus on increasing LRT ridership in urban areas where LRT is available. Policy recommendations resulting from the conclusions of this study are focused on directing existing environmental, energy and transportation policies to increase light rail transit ridership. As presented in Table 5.2, the results of the comparative modal analysis indicate that light rail transit becomes the least energy intensive and least CO_2 emissions intensive compared to other rail transit modes and bus system when light rail ridership is increased by at least 63 percent from the existing 2011 ridership levels. Based on available 2011 data from the National Transit Database, ridership levels for light rail is at 434 million in 2011. Light rail ridership should increase to about 708 million to be able to be less energy intensive and less CO_2 emissions intensive than heavy rail, commuter rail and bus systems. Policy recommendations and strategies for increasing ridership include, but not limited to the following needs:

a) additional public relations campaign on the benefits of riding light rail transit for urban areas that have existing LRT systems in place;
b) additional light rail presence in urban areas as an alternative public transit option, although this requires a thorough feasibility study as well as capital outlay and investments from government and private sector partnerships;
c) incentives to ride light rail instead of privately owned vehicles through fare pricing, fuel tax incentives, subsidies;
d) provisions for park and ride facilities within the proximity of light rail transit station.

These policy recommendations require budget appropriations, legislation and other policy discussions for implementing and operating light rail transit systems. The decision to build light rail transit systems on urban areas depends on the demand for rail transit and other considerations such as population growth, economic feasibility and public transit ridership. In addition, the cultural aspect and attitudes toward riding light rail and other forms of public transit should be considered. In the United States, majority of the population still prefer to ride their privately owned vehicles instead of public transit for ease of mobility and convenience. Providing access to public transit options may not be sufficient when public attitudes and demand for public transit is low. In essence, establishing a light rail transit system is dependent on whether people will actually ride light rail transit when available. This applies also to other more energy efficient forms of public transportation. Hence, in considering choices for building and operating public transit systems as well as high volume highways, all aspects of environmental, economic and social sustainability must be covered in the analysis to be able to provide a comprehensive view on whether public transit systems adhere to the principles of the sustainable transportation agenda.

Limitations of the Study

While this study provided empirical evidence on the relationship between LRT and environmental sustainability indicators and possible determinants, the study has many limitations. While the study is guided by the triple bottom line aspects of sustainability, the primary focus of this analysis is focused on environmental sustainability. However, discussions indirectly cover the social and economic aspects of sustainable transportation, especially when trying to provide an explanation why LRT presence is significant for air quality and energy consumption per capita, but not significant for energy intensity and CO_2 emissions variables. In addition, the study did not cover the institutional and political aspects of sustainability. From a conceptual framework, the role of institutions and politics can provide additional insights and explanations to the relationships between LRT and sustainability.

As a form of empirical evidence, the findings of this study reinforces the notion that light rail has environmental sustainability impacts. However, the findings of this study are also limited to urban areas, and are limited to available data and measurement variables in the existing statistical system. The definitions and the measurement of the variables used in the study may change over time to capture the changes in the units of analysis and other factors, which may alter and be different from the initial findings of the study.

While the impact of light rail on environmental sustainability in urban areas is examined, this study also takes into account the areas that have other forms of rail transit in the urban areas, such as heavy rail and commuter rail. The presence of other forms of public transit may also affect environmental sustainability in the area, and the results of the analysis can broaden the understanding on the benefits of rail transit in general on environmental sustainability.

Bus systems are not included in the empirical analysis of study. Bus systems have been initially considered for this study together with other passenger rail transit modes. However, all the urban areas covered in the study have bus systems in place, thereby providing no variation for comparison. Bus systems, on the other hand, are included in some policy discussions in the study, but the transit modes considered in this study are passenger rail modes.

The policy discussions and the results of the study do not directly address the following issues: a) policy debates on which transit option is a better alternative for urban areas; b) comparison between light rail systems and bus systems; c) comparison between rail investments and highway investments; and d) light rail impacts on urban development patterns. Focus on light rail and environmental sustainability provides additional value on the literature for sustainable transportation and sustainable public transit options.

The discussions for this study are focused on light rail presence and environmental sustainability goals. The resulting analysis does not make conclusions on the overall sustainability of light rail systems since the study is only focused on one of the three aspects of sustainable transportation. The three aspects of sustainable transportation, also referred to as the “triple bottom line” are social, economic and environmental sustainability.

Finally, data used as environmental sustainability indicators are limited to data and information that are available in the existing statistical system. Data for variables that represent possible determinants of environmental sustainability are also limited to available data and information at the geographic area level of analysis. The available data and information provided a constraint in covering the analysis of all the environmental sustainability goals that are provided in sustainable transportation definition (Hall, 2006). Since secondary data is used, there are may be missing values in the dataset and the author has no control over the validity of data that was entered in the databases at the time of research. In addition to missing values, test for the measurement validity of the variables used in the study are limited. While collinearity issues have been addressed in the regression analysis, a possible endogeneity problem with the variables was not explicitly addressed in the analysis and discussion. Additional tests and variables that were previously omitted should be included in future analysis related to the environmental sustainability of LRT systems

With respect to the overall research goals for this study, the results of the analysis provide the relationships among dependents and independent variables through empirical data. Other considerations to be included in selecting additional variables to improve this research may include the purposes and motivations why LRT is built and operated in urban areas, the regional effects, city effects, and the attitudes of the public on LRT ridership, environmental sustainability and identifying factors that motivate and enable people to ride the LRT and other public transit.

Suggestions for Further Research

Given the findings of the study, suggestions for further research include addressing the limitations of the study and improving the analysis of LRT and sustainability. Additional environmental sustainability indicators can be identified and included in this study, provided that data is available at the urban area level. Suggestions include indicators for other environmental sustainability goals that were not covered in this study such as minimizing health and environmental damage, maintaining high environmental quality and human health standards, minimizing the production of noise, minimizing the use of land, and recycling. These additional environmental sustainability goals are based on the definition of sustainable transportation compiled by Hall (2006).

A comparative modal analysis on energy consumption and CO2 emissions indicated that based on data from 2011, light rail is not the least energy intensive, and least CO2 emissions intensive among other modes of rail transit and bus systems. A similar method of analysis used in this study focusing on heavy rail presence, commuter rail presence and bus system presence can be conducted using specific modal characteristics similar to the variables used for light rail. While the models for the first research question addressed heavy rail and commuter rail presence, the analysis can be enhanced with the inclusion of heavy rail and commuter rail characteristics as independent variables, and compared with light rail impacts.

Other statistical and regression analysis approaches can also be utilized in future analysis that captures all aspects of environmental sustainability and sustainable transportation. The use of the fixed effects models in the regression analysis enhanced the analysis by removing possible confounding and spurious variables brought about my certain conditions and events that may also influence environmental sustainability. Other statistical and econometric modeling approaches include the use of structural models, general equilibrium models and other techniques for analysis.

A similar approach for analysis used in this study can be utilized in considering other aspects of sustainability, such as economic, social and institutional sustainability. By identifying measurable goals for each of these aspects, and finding relevant and measurable indicators for the same geographical urban area level, the same analysis using the same dataset can also be conducted. By covering all aspects of sustainability, a more comprehensive picture can be provided on the state of LRT systems as a sustainable public transit option.

Final Note

As a final note, the results of this analysis established a small portion of improving the understanding of the environmental sustainability of light rail systems. This dissertation only focused on one aspect of sustainable transportation (environmental sustainability) and on one mode of public transit (light rail transit). Suggestions for further research include expanding the focus of the study on other aspects of sustainability such as economic and social sustainability. Aside from expanding this study to other aspects of sustainability, analysis can also be expanded to other modes of transportation, specifically for public transit. Further research is also encouraged for identifying additional sustainability indicators and for discussing other possible determinants for sustainability.

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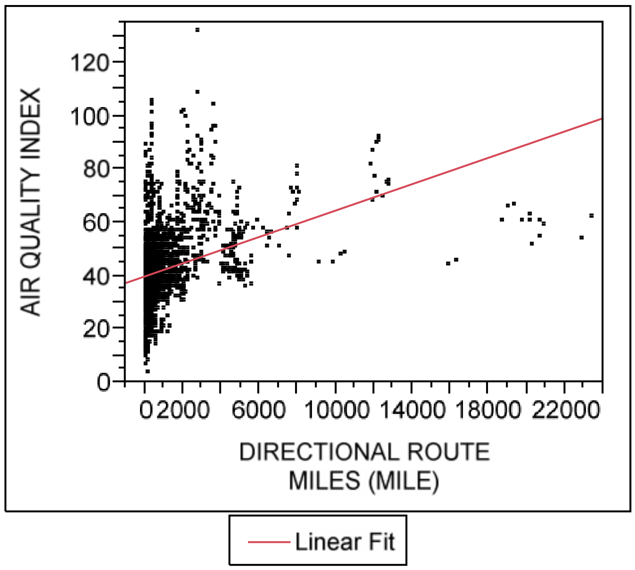
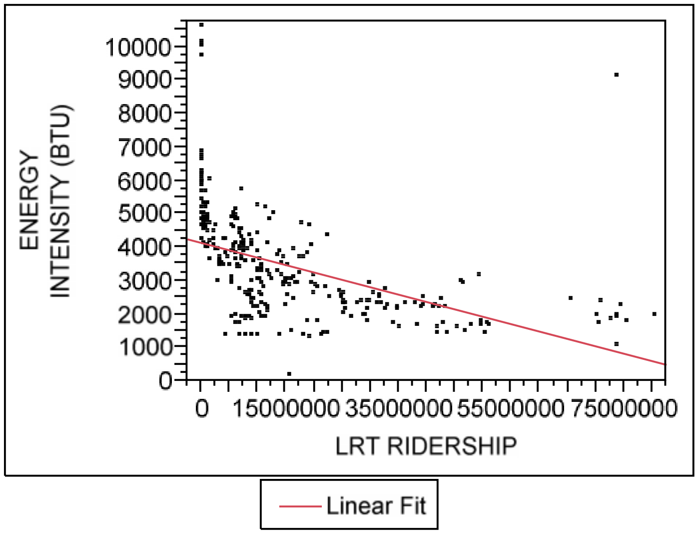
APPENDIX A: BIVARIATE FIT ANALYSIS RESULTS

The following figures show the bivariate fits of statistically significant models that have R-square values with larger than 10 percent of variances explained.



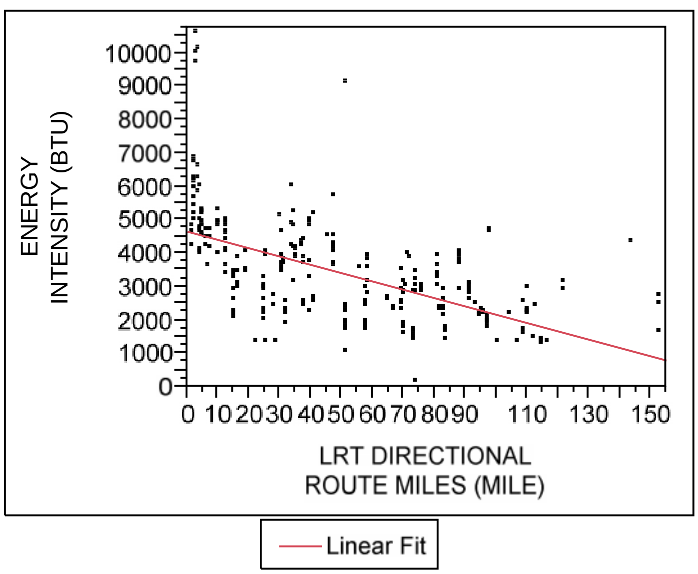
Linear Fit: AIR QUALITY INDEX = 39.786351 + 0.0024794*DIRECTIONAL ROUTE MILES (MILE)
Source: Author's Calculation

Figure A.1: Bivariate fit for Air quality index and directional route miles



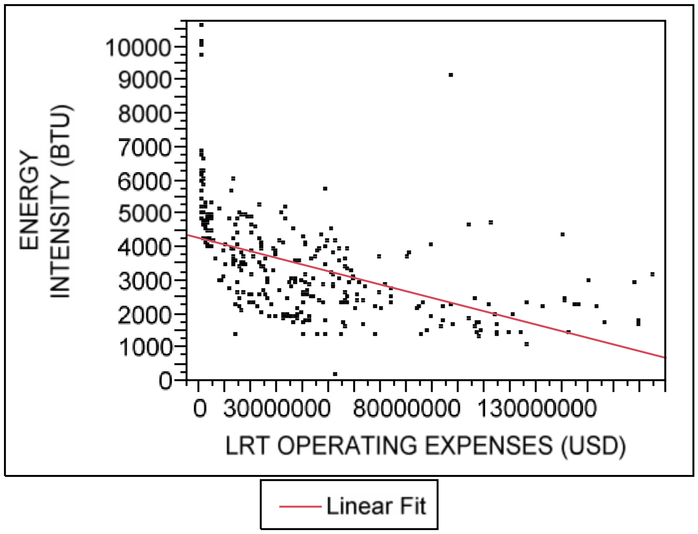
Linear Fit: ENERGY INTENSITY (BTU) = 4127.1301 - 4.4255e-5*LRT RIDERSHIP
Source: Author’s Calculation

Figure A.2: Bivariate fit for energy intensity and LRT ridership



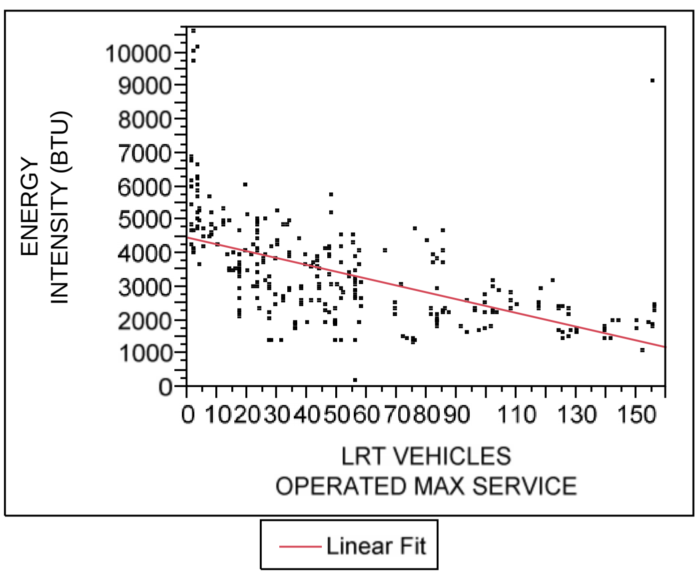
Linear Fit: ENERGY INTENSITY (BTU) = 4641.6708 - 24.864632*LRT DIRECTIONAL ROUTE MILES (MILE)
Source: Author’s Calculation

Figure A.3: Bivariate fit for energy intensity and LRT directional route miles



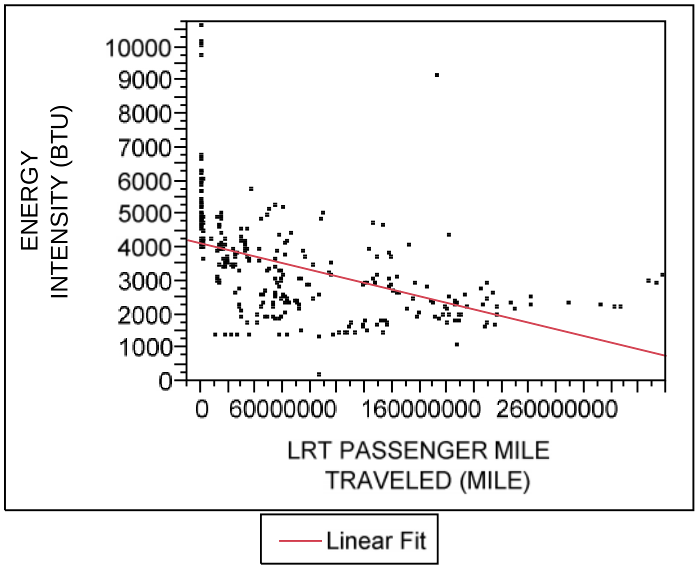
Linear Fit: ENERGY INTENSITY (BTU) = 4269.301 - 0.0000199*LRT OPERATING EXPENSES (USD)
Source: Author's Calculation

Figure A.4: Bivariate fit for energy intensity and LRT operating expenses



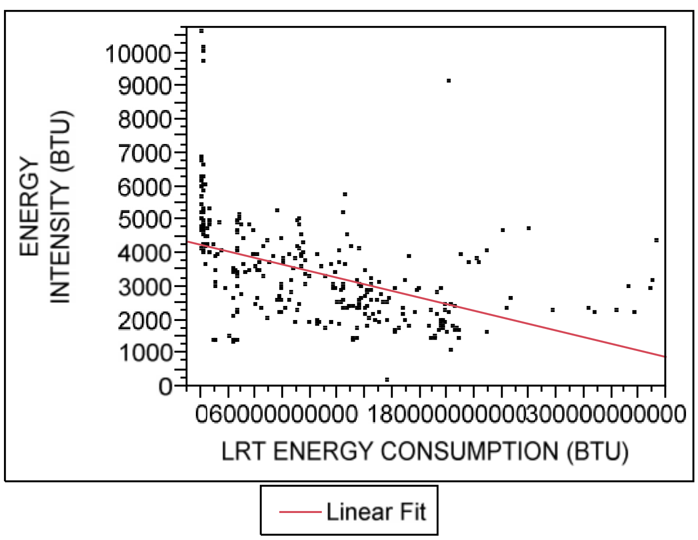
Linear Fit: ENERGY INTENSITY (BTU) = 4469.5016 - 20.531588*LRT VEHICLES OPERATED MAX SERVICE
Source: Author's Calculation

Figure A.5: Bivariate fit for energy intensity and LRT vehicles operating at maximum service



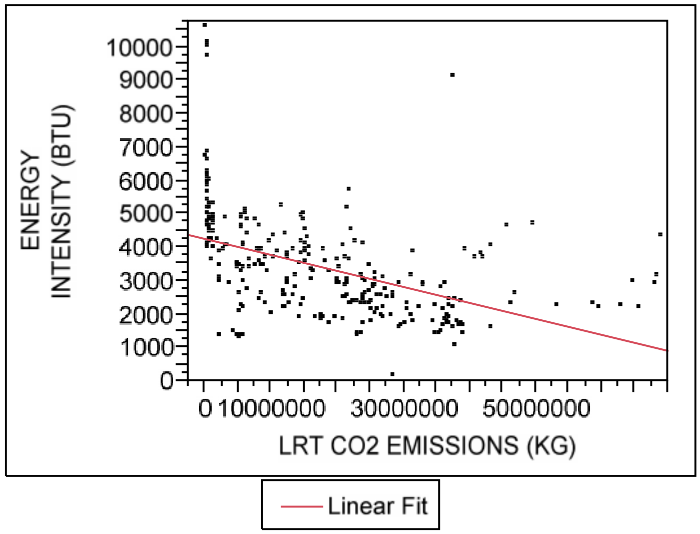
Linear Fit: ENERGY INTENSITY (BTU) = 4125.9405 - 9.8986e-6*LRT PASSENGER MILES TRAVELED (MILE)
Source: Author's Calculation

Figure A.6: Bivariate fit for energy intensity and LRT passenger miles traveled



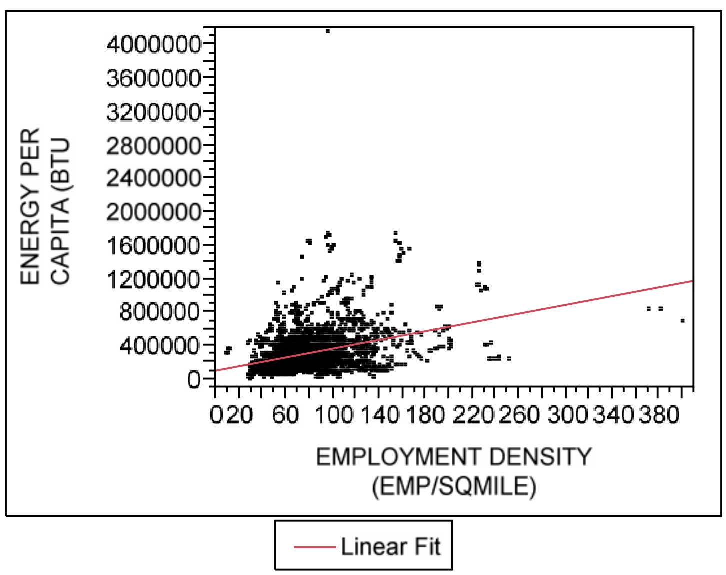
Linear Fit: ENERGY INTENSITY (BTU) = 4247.1922 - 9.8797e-9*LRT ENERGY CONSUMPTION (BTU)
Source: Author's Calculation

Figure A.7: Bivariate fit for energy intensity and LRT energy consumption



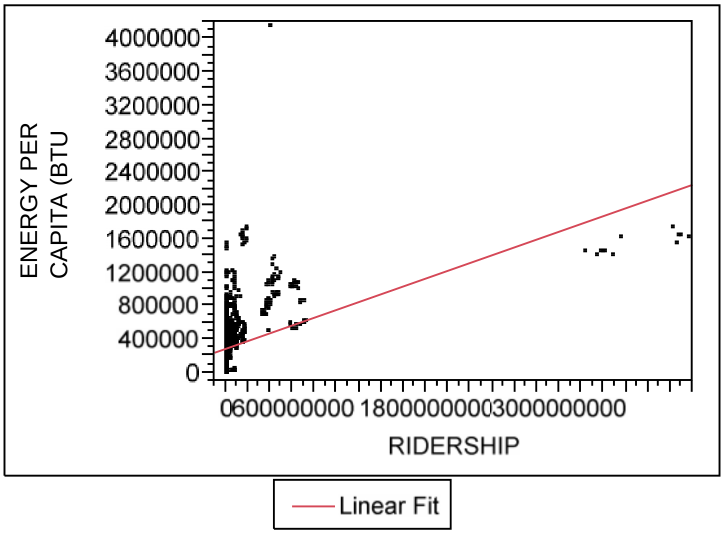
Linear Fit: ENERGY INTENSITY (BTU) = 4247.1923 - 4.7775e-5*LRT CO2 EMISSIONS (KG)
Source: Author’s Calculation

Figure A.8: Bivariate fit for energy intensity and CO2 emissions



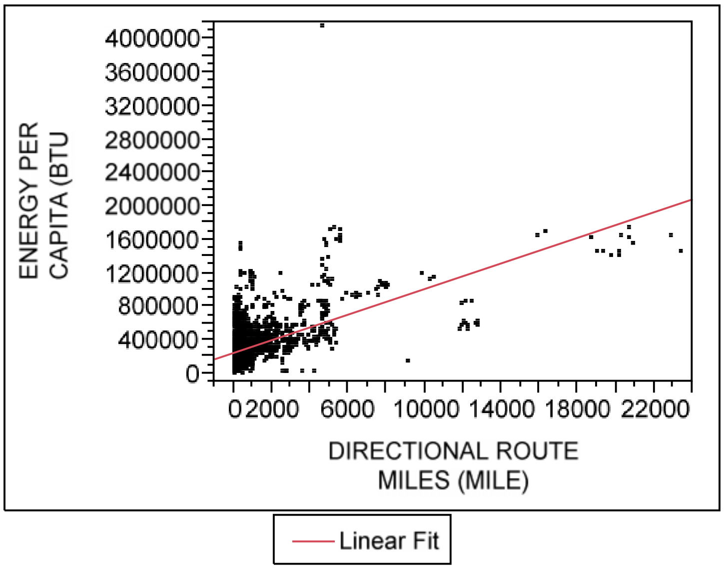
Linear Fit: ENERGY PER CAPITA (BTU) = 100782.7 + 2628.4369*EMPLOYMENT DENSITY (EMP/SQMILE)
Source: Author’s Calculation

Figure A.9: Bivariate fit for energy consumption per capita and employment density



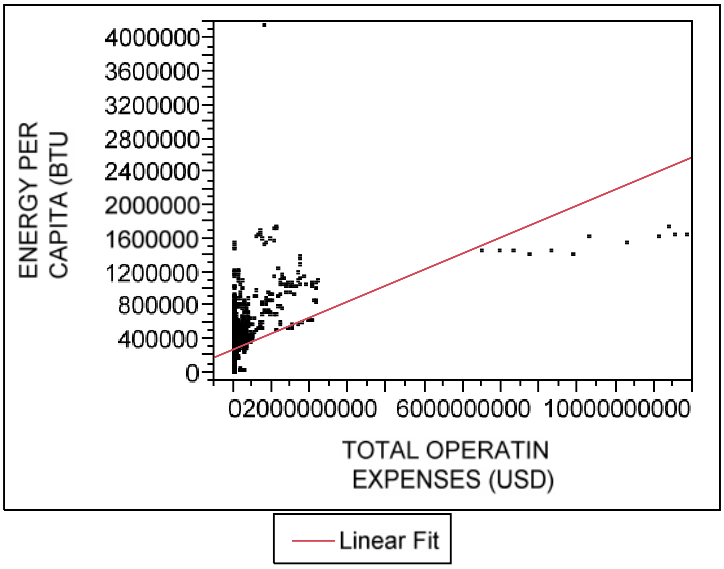
Linear Fit: ENERGY PER CAPITA (BTU) = 284115.92 + 0.0004682*RIDERSHIP
Source: Author's Calculation

Figure A.10: Bivariate fit for energy consumption per capita and ridership



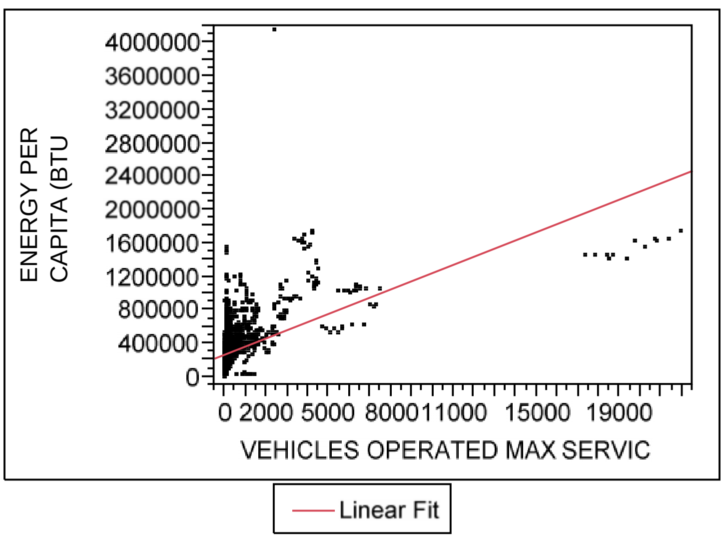
Linear Fit: ENERGY PER CAPITA (BTU) = 242600.2 + 76.651203*DIRECTIONAL ROUTE MILES (MILE)
Source: Author's Calculation

Figure A.11: Bivariate fit for energy consumption per capita and directional route miles



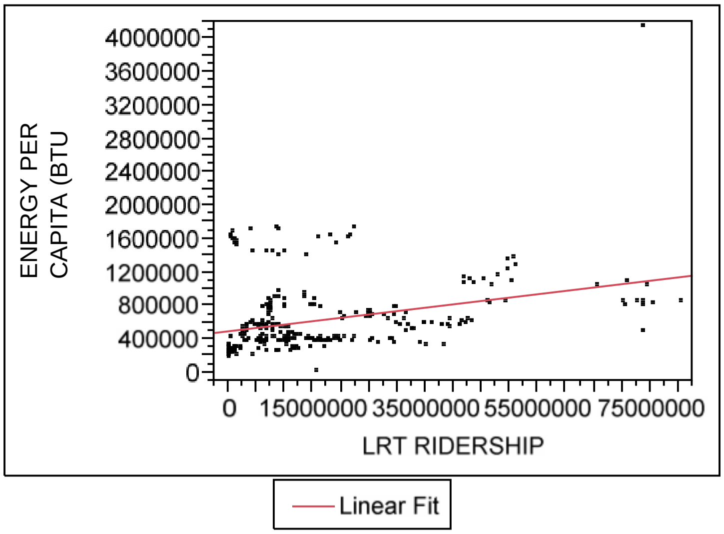
Linear Fit: ENERGY PER CAPITA (BTU) = 280566.74 + 0.0001918*TOTAL OPERATING EXPENSES (USD)
Source: Author's Calculation

Figure A.12: Bivariate fit for energy consumption per capita and operating expenses



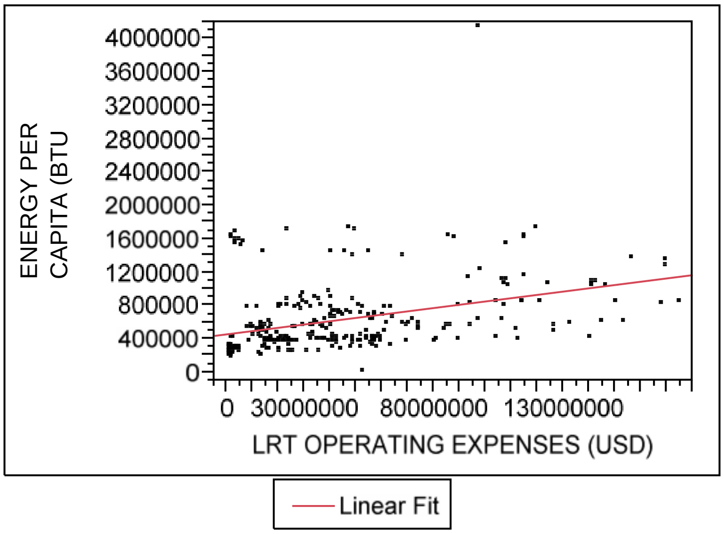
Linear Fit: ENERGY PER CAPITA (BTU) = 267030.79 + 97.896722*VEHICLES OPERATED MAX SERVICE
Source: Author's Calculation

Figure A.13: Bivariate fit for energy consumption per capita and vehicles operating at maximum service



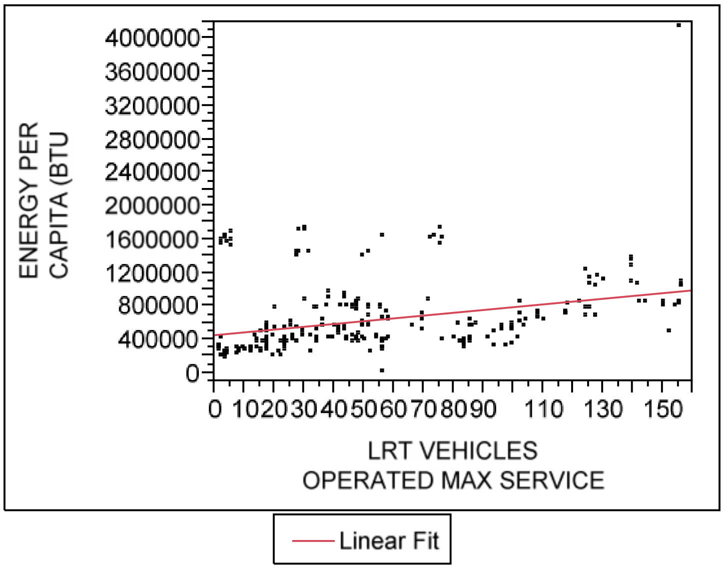
Linear Fit: ENERGY PER CAPITA (BTU) = 495500.39 + 0.0080474*LRT RIDERSHIP
Source: Author's Calculation

Figure A.14: Bivariate fit for energy consumption per capita and LRT ridership



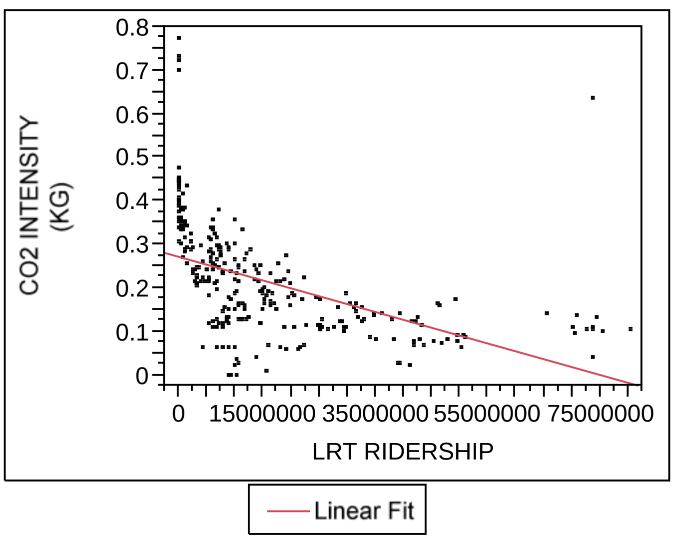
Linear Fit: ENERGY PER CAPITA (BTU) = 455284.83 + 0.0039512*LRT OPERATING EXPENSES (USD)
Source: Author's Calculation

Figure A.15: Bivariate fit for energy consumption per capita and LRT operating expenses



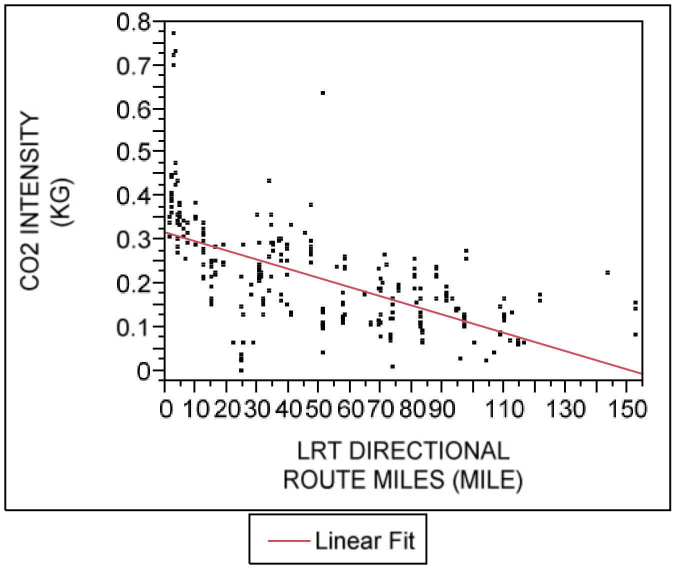
Linear Fit: ENERGY PER CAPITA (BTU) = 452515.02 + 3358.44*LRT VEHICLES OPERATED MAX SERVICE
Source: Author's Calculation

Figure A.16: Bivariate fit for energy consumption per capita and vehicles operating at maximum service



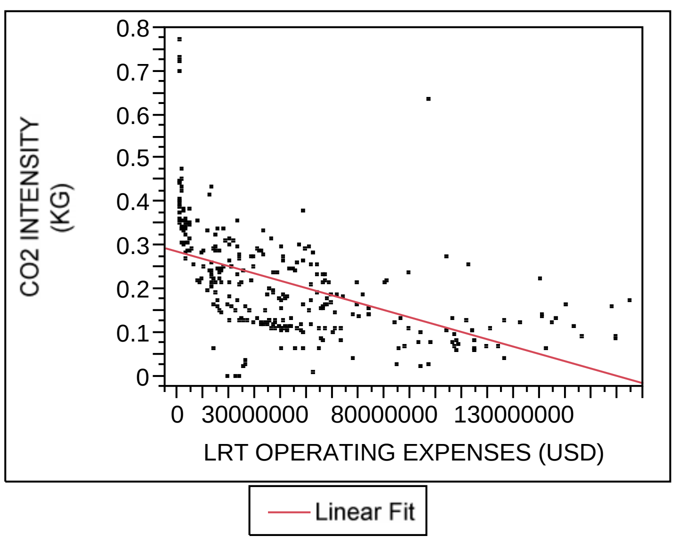
Linear Fit: CO2 INTENSITY (KG) = 0.2716992 - 3.6271e-9*LRT RIDERSHIP
Source: Author's Calculation

Figure A.17: Bivariate fit for CO_2 intensity and LRT ridership



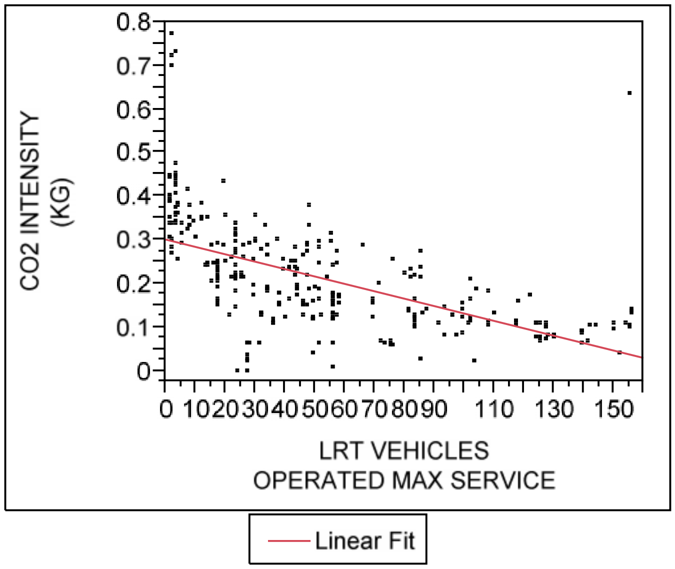
Linear Fit: CO2 INTENSITY (KG) = 0.3167035 - 0.0020959*LRT DIRECTIONAL ROUTE MILES (MILE)
Source: Author's Calculation

Figure A.18: Bivariate fit for CO_2 intensity and LRT directional route miles



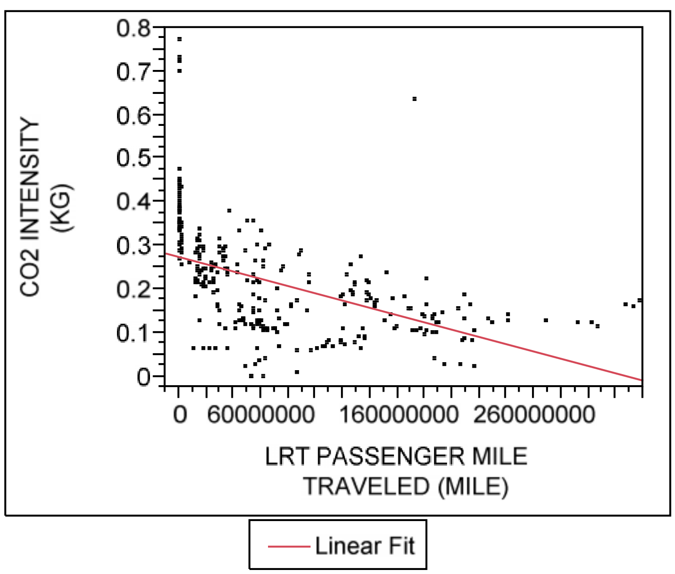
Linear Fit: CO2 INTENSITY (KG) = 0.2854843 - 1.6799e-9*LRT OPERATING EXPENSES (USD)
Source: Author's Calculation

Figure A.19: Bivariate fit for CO_2 intensity and LRT operating expenses



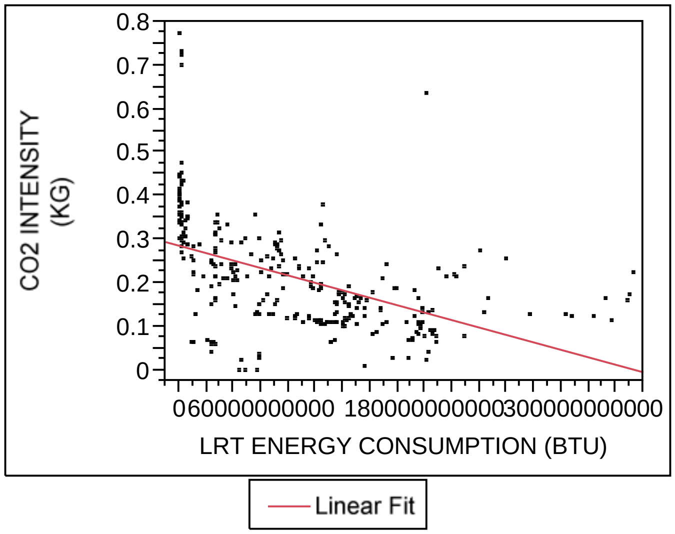
Linear Fit: CO2 INTENSITY (KG) = 0.3005286 - 0.0016977*LRT VEHICLES OPERATED MAX SERVICE
Source: Author's Calculation

Figure A.20: Bivariate fit for CO_2 intensity and LRT vehicles operating at maximum service



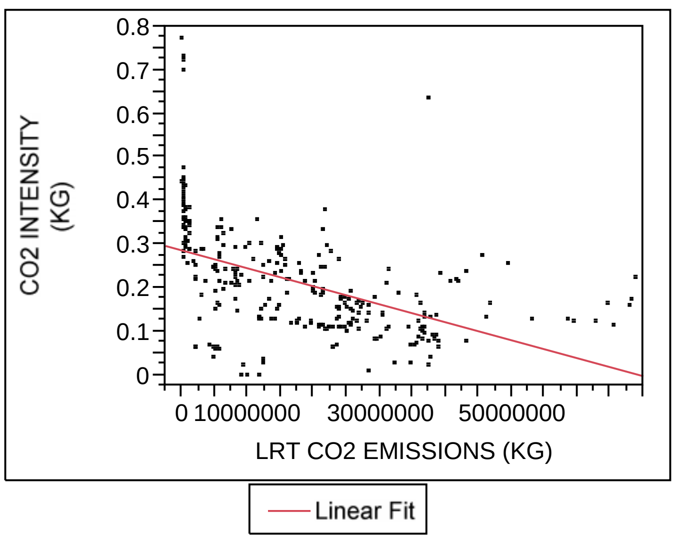
Linear Fit: CO2 INTENSITY (KG) = 0.2738028 - 8.37e-10*LRT PASSENGER MILES TRAVELED (MILE)
Source: Author's Calculation

Figure A.21: Bivariate fit for CO_2 intensity and LRT passenger miles traveled



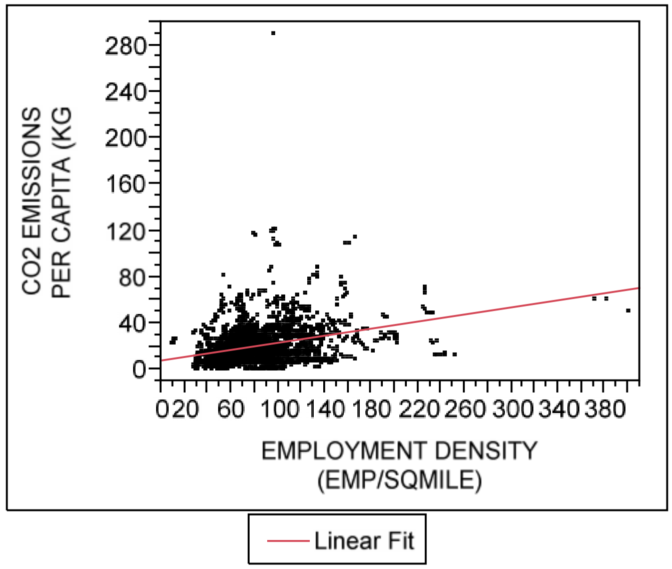
Linear Fit: CO2 INTENSITY (KG) = 0.2852573 - 8.538e-13*LRT ENERGY CONSUMPTION (BTU)
Source: Author's Calculation

Figure A.22: Bivariate fit for CO2 intensity and LRT energy consumption



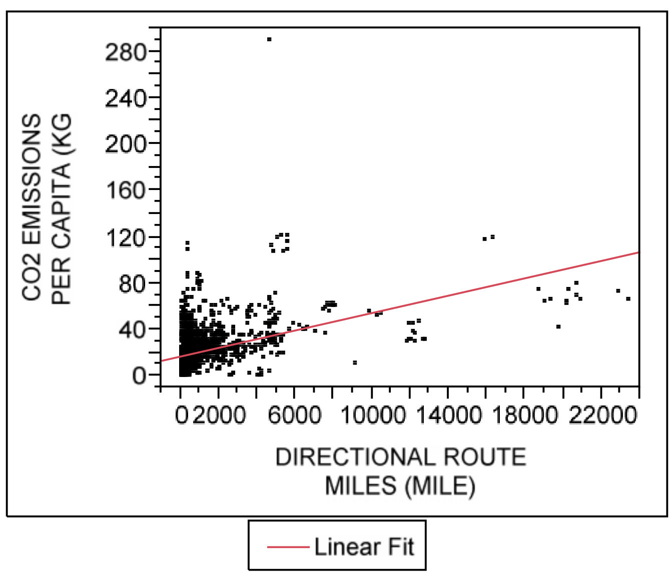
Linear Fit: CO2 INTENSITY (KG) = 0.2852573 - 4.1289e-9*LRT CO2 EMISSIONS (KG)
Source: Author's Calculation

Figure A.23: Bivariate fit for CO2 intensity and CO2 emissions



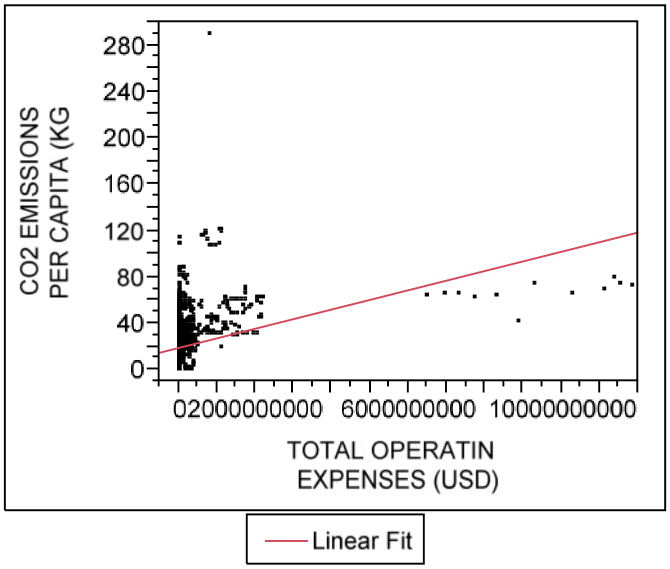
Linear Fit: CO2 EMISSIONS PER CAPITA (KG) = 8.1103816 + 0.1524928*EMPLOYMENT DENSITY (EMP/SQMILE)
Source: Author's Calculation

Figure A.24: Bivariate fit for CO2 emissions per capita and employment density



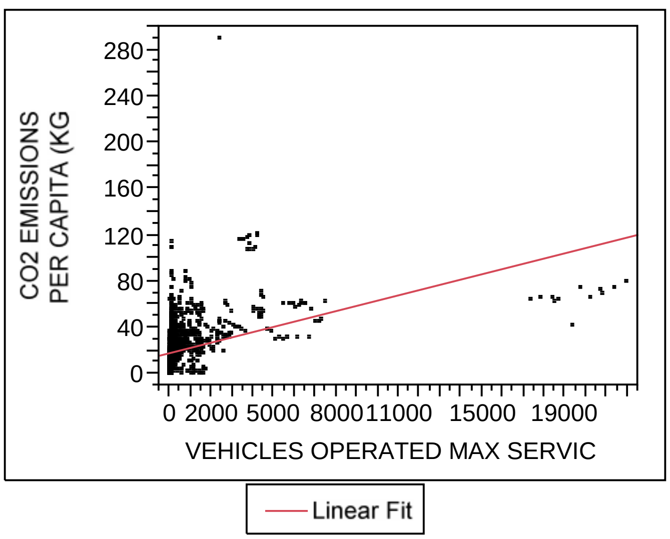
Linear Fit: CO2 EMISSIONS PER CAPITA (KG) = 16.898491 + 0.0037463*DIRECTIONAL ROUTE MILES (MILE)
Source: Author's Calculation

Figure A.25: Bivariate fit for CO2 emissions per capita and directional route miles



Linear Fit: CO2 EMISSIONS PER CAPITA (KG) = 18.823837 + 8.3173e-9*TOTAL OPERATING EXPENSES (USD)
Source: Author's Calculation

Figure A.26: Bivariate fit for CO2 emissions per capita and operating expenses



Linear Fit: CO2 EMISSIONS PER CAPITA (KG) = 18.131473 + 0.0045359*VEHICLES OPERATED MAX SERVICE
Source: Author's Calculation

Figure A.27: Bivariate fit for CO2 emissions per capita and vehicles operating at maximum service

APPENDIX B: SUMMARY OF REGRESSION ANALYSIS RESULTS

Research Question #1 (RQ1): How does light rail presence affect environmental sustainability indicators in urban areas?

First Round Regressions

Table B.1: RQ1 first round of regressions for air quality index – basic model

Variables	OLS		Fixed Effects	
Constant	39.793	*	42.316	*
	(0.197)		(0.643)	
LRT Presence	15.296	*	15.363	*
	(1.001)		(0.993)	
CRT Presence	2.268		2.777	
	(2.122)		(2.105)	
HRT Presence	18.624	*	18.643	*
	(3.509)		(3.480)	
LRT*CRT	-7.245	*	-7.349	*
	(2.956)		(2.932)	
LRT*HRT	-8.171		-8.238	
	(5.055)		(5.013)	
CRT*HRT	-6.279		-6.737	
	(4.556)		(4.518)	
LRT*CRT*HRT	3.518		3.542	
	(6.272)		(6.220)	
Years				
2001			-0.643	
			(0.907)	
2002			-1.282	
			(0.908)	
2003			-1.784	*
			(0.908)	
2004			-3.007	*
			(0.912)	
2005			-1.509	
			(0.911)	
2006			-2.238	*
			(0.913)	
2007			-1.711	
			(0.914)	
2008			-3.471	*
			(0.914)	
2009			-5.951	*
			(0.910)	

Table B.1: (continued)

Variables	OLS		Fixed Effects	
2010			-4.353	*
			(0.911)	
2011			-4.460	*
			(0.911)	
R-square	0.112		0.129	
N	4164		4164	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05

Year 2000 is omitted, naturally coded.

Table B.2: RQ1 first round of regressions for air quality index – expanded model

Variables	OLS		Fixed Effects	
Constant	37.613	*	42.162	*
	(0.663)		(1.009)	
LRT Presence	6.947	*	6.749	*
	(1.106)		(1.089)	
CRT Presence	-3.386		-2.880	
	(2.052)		(2.020)	
HRT Presence	10.148	*	10.037	*
	(3.393)		(3.340)	
LRT*CRT	-7.383	*	-7.887	*
	(2.917)		(2.872)	
LRT*HRT	1.509		1.312	
	(4.850)		(4.774)	
CRT*HRT	-12.021	*	-13.311	*
	(4.463)		(4.395)	
LRT*CRT*HRT	3.429		4.806	
	(6.141)		(6.046)	
Population Density	2.08E-03	*	2.17E-03	*
	(3.91E-03)		(3.86E-04)	
Housing Density	4.11E-04	*	5.15E-04	*
	(1.04E-04)		(1.03E-04)	
Employment Density	-5.06E-02	*	-6.04E-02	*
	(8.18E-03)		(8.13E-03)	
Ridership	-2.47E-09		-1.43E-08	*
	(7.03E-09)		(7.03E-09)	

Table B.2: (continued)

Variables	OLS		Fixed Effects	
Directional Route Miles	4.15E-03	*	4.14E-03	*
	(3.64E-04)		(3.59E-04)	
Operating Expenses	-6.09E-09	*	-7.97E-10	
	(2.97E-09)		(2.98E-09)	
Vehicles at Max Service	4.78E-05		-1.82E-04	
	(1.12E-03)		(1.10E-03)	
Years				
2001			-0.927	
			(1.081)	
2002			-2.358	*
			(1.083)	
2003			-3.053	*
			(1.049)	
2004			-4.504	*
			(1.048)	
2005			-3.060	*
			(1.046)	
2006			-4.043	*
			(1.049)	
2007			-3.374	*
			(1.047)	
2008			-5.262	*
			(1.050)	
2009			-8.006	*
			(1.044)	
2010			-6.550	*
			(1.044)	
2011			-6.239	*
			(1.068)	
R-square	0.224		0.251	
N	2984		2984	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05

Year 2000 is omitted, naturally coded.

Table B.3: RQ1 first round of regressions for energy intensity – basic model

Variables	OLS		Fixed Effects	
Constant	7953.975	*	6924.601	*
	(370.419)		(1286.442)	
LRT Presence	-3975.494	*	-4073.479	*
	(1634.702)		(1633.740)	
CRT Presence	-4748.745		-4578.164	
	(3568.697)		(3565.726)	
HRT Presence	-5989.981		-6042.999	
	(5897.692)		(5891.121)	
LRT*CRT	4158.140		4183.994	
	(4950.702)		(4945.478)	
LRT*HRT	5787.050		5885.034	
	(8483.123)		(8473.657)	
CRT*HRT	18507.050	*	18369.290	*
	(7656.210)		(7647.909)	
LRT*CRT*HRT	-19606.470		-19682.240	
	(10530.550)		(10518.950)	
Years				
2001			2080.636	
			(1795.207)	
2002			518.779	
			(1796.895)	
2003			925.988	
			(1793.531)	
2004			3726.616	*
			(1809.137)	
2005			4738.715	*
			(1778.971)	
2006			372.401	
			(1772.790)	
2007			-44.242	
			(1765.208)	
2008			-392.029	
			(1762.259)	
2009			518.449	
			(1684.027)	
2010			375.319	
			(1679.086)	
2011			-131.924	
			(1738.040)	

Table B.3: (continued)

Variables	OLS	Fixed Effects
R-square	0.006	0.012
N	3404	3404

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.4: RQ1 first round of regressions for energy intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	10091.850	*	9321.068	*
	(1158.372)		(1780.269)	
LRT Presence	-1383.373		-1492.162	
	(1839.228)		(1837.801)	
CRT Presence	-3138.928		-2963.006	
	(3441.427)		(3436.247)	
HRT Presence	-5024.025		-5016.758	
	(5688.444)		(5677.848)	
LRT*CRT	6016.792		6042.332	
	(4891.655)		(4883.610)	
LRT*HRT	3932.075		3959.960	
	(8124.900)		(8109.722)	
CRT*HRT	23664.950	*	23462.410	*
	(7479.764)		(7468.333)	
LRT*CRT*HRT	-23494.270	*	-23496.350	*
	(10295.070)		(10278.570)	
Population Density	-1.648	*	-1.549	*
	(0.723)		(0.723)	
Housing Density	-0.132		-0.106	
	(0.186)		(0.187)	
Employment Density	17.896		14.530	
	(16.392)		(16.501)	
Ridership	1.48E-05		1.36E-05	
	(1.18E-05)		(1.20E-05)	
Directional Route Miles	0.403		0.401	
	(0.609)		(0.608)	
Operating Expenses	2.35E-06		3.09E-06	
	(5.00E-06)		(5.08E-06)	

Table B.4: (continued)

Variables	OLS		Fixed Effects	
Vehicles at Max Service	-4.355	*	-4.490	*
	(1.877)		(1.875)	
Years				
2001			-26.611	
			(1883.257)	
2002			594.550	
			(1893.967)	
2003			778.912	
			(1840.208)	
2004			3919.317	*
			(1852.230)	
2005			5067.781	*
			(1826.917)	
2006			51.111	
			(1822.099)	
2007			-377.420	
			(1815.574)	
2008			-508.426	
			(1815.360)	
2009			296.727	
			(1764.381)	
2010			403.688	
			(1763.927)	
2011			-219.646	
			(1824.118)	
R-square	0.013		0.021	
N	2948		2948	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.5: RQ1 first round of regressions for energy consumption per capita – basic model

Variables	OLS		Fixed Effects	
Constant	267232.500	*	258120.900	*
	(7381.518)		(25829.560)	
LRT Presence	160067.500	*	162715.500	
	(32804.190)		(32788.380)	
CRT Presence	114451.300		112102.400	
	70585.680		(70550.770)	
HRT Presence	158899.200		159475.200	
	(118392.300)		(118281.700)	
LRT*CRT	253341.600	*	251191.200	*
	(98626.730)		(98540.600)	
LRT*HRT	-51872.200		-54520.110	
	(170295.600)		(170136.300)	
CRT*HRT	297337.300		298923.500	
	(153208.600)		(153072.700)	
LRT*CRT*HRT	-213842.300		-210531.700	
	(211044.600)		(210847.500)	
Years				
2001			1188.233	
			(36011.580)	
2002			92232.010	*
			(35944.940)	
2003			-4582.253	
			(35879.100)	
2004			-8181.416	
			(35751.000)	
2005			-13748.060	
			(35563.450)	
2006			-16904.930	
			(35473.190)	
2007			-14209.230	
			(35324.790)	
2008			-11455.100	
			35354.230	
2009			23796.430	
			(33751.800)	
2010			17534.640	
			(33693.020)	
2011			36757.260	
			(34863.020)	
R-square	0.097		0.102	
N	3450		3450	

Table B.5: (continued)

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.6: RQ1 first round of regressions for energy consumption per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	133372.700	*	132746.900	*
	(10815.770)		(16625.120)	
LRT Presence	40164.020	*	43731.150	*
	(17212.330)		(17171.490)	
CRT Presence	54572.560		51697.350	
	(32208.880)		(32109.970)	
HRT Presence	95031.720		95596.980	
	(53239.440)		(53056.460)	
LRT*CRT	121137.400	*	119434.000	*
	(45780.960)		(45633.450)	
LRT*HRT	44722.420		42914.610	
	(76044.070)		(75782.280)	
CRT*HRT	-58679.240		-53934.120	
	(70002.510)		(69786.250)	
LRT*CRT*HRT	-99055.860		-98065.850	
	(96354.410)		(96048.350)	
Population Density	25.963	*	23.320	*
	(6.748)		(6.745)	
Housing Density	5.928	*	5.167	*
	(1.739)		(1.743)	
Employment Density	826.641	*	913.460	*
	(152.745)		(153.540)	
Ridership	-0.001	*	-0.001	*
	(1.11E-04)		(1.12E-04)	
Directional Route Miles	-12.024	*	-12.244	*
	(5.692)		(5.680)	
Operating Expenses	2.50E-05		1.05E-05	
	(4.68E-05)		(4.74E-05)	
Vehicles at Max Service	205.079	*	207.183	*
	(17.565)		(17.515)	
Years				
2001			1335.766	
			(17578.070)	

Table B.6: (continued)

Variables	OLS	Fixed Effects
2002		17379.030
		(17677.360)
2003		-9372.000
		(17149.180)
2004		-14597.170
		(17073.240)
2005		-19732.230
		(16994.400)
2006		-22118.480
		(17011.510)
2007		-18234.400
		(16951.110)
2008		-14794.880
		(16963.820)
2009		24853.880
		(16487.330)
2010		18791.010
		(16482.970)
2011		32181.670
		(17045.290)
R-square	0.452	0.457
N	2974	2974

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.7: RQ1 first round of regressions for CO2 intensity – basic model

Variables	OLS		Fixed Effects	
Constant	0.555	*	0.497	*
	(0.027)		(0.094)	
LRT Presence	-0.293	*	-0.301	*
	(0.120)		(0.120)	
CRT Presence	-0.341		-0.324	
	(0.262)		(0.262)	
HRT Presence	-0.457		-0.461	
	(0.433)		(0.432)	

Table B.7: (continued)

Variables	OLS	Fixed Effects	
LRT*CRT	0.278	0.280	
	(0.363)	(0.363)	
LRT*HRT	0.422	0.429	
	(0.623)	(0.622)	
CRT*HRT	0.975	0.960	
	(0.562)	(0.561)	
LRT*CRT*HRT	-1.029	-1.034	
	(0.773)	(0.772)	
Years			
2001		0.150	
		(0.132)	
2002		0.032	
		(0.132)	
2003		0.066	
		(0.132)	
2004		0.263	
		(0.133)	
2005		0.338	*
		(0.131)	
2006		0.014	
		(0.131)	
2007		-0.022	
		(0.131)	
2008		-0.060	
		(0.131)	
2009		0.001	
		(0.124)	
2010		0.006	
		(0.124)	
2011		-0.046	
		(0.129)	
R-square	0.005	0.011	
N	3336	3336	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.8: RQ1 first round of regressions for CO2 intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	0.725	*	0.693	*
	(0.086)		(0.131)	
LRT Presence	-0.101		-0.111	
	(0.136)		(0.136)	
CRT Presence	-0.215		-0.197	
	(0.254)		(0.253)	
HRT Presence	-0.390		-0.389	
	(0.420)		(0.419)	
LRT*CRT	0.349		0.348	
	(0.361)		(0.360)	
LRT*HRT	0.292		0.293	
	(0.599)		(0.598)	
CRT*HRT	1.291	*	1.265	*
	(0.552)		(0.551)	
LRT*CRT*HRT	-216711.000		-1.207	
	(0.759)		(0.758)	
Population Density	-1.27E-04	*	-1.18E-04	*
	(5.35E-05)		(5.36E-05)	
Housing Density	-8.64E-06		-5.86E-06	
	(1.37E-05)		(1.38E-05)	
Employment Density	1.30E-03		0.001	
	(1.22E-03)		(1.22E-03)	
Ridership	8.52E-10		6.78E-10	
	(8.71E-10)		(8.83E-10)	
Directional Route Miles	5.53E-06		5.14E-06	
	(4.49E-05)		(4.49E-05)	
Operating Expenses	7.49E-11		1.71E-10	
	(3.69E-10)		(3.74E-10)	
Vehicles at Max Service	-2.06E-04		-2.18E-04	
	(1.39E-04)		(1.38E-04)	
Years				
2001			-0.004	
			(0.139)	
2002			0.035	
			(0.140)	
2003			0.053	
			(0.136)	
2004			0.273	*
			(0.137)	
2005			0.359	*
			(0.135)	

Table B.8: (continued)

Variables	OLS	Fixed Effects
2006		-0.014
		(0.135)
2007		-0.050
		(0.135)
2008		-0.074
		(0.135)
2009		-0.022
		(0.131)
2010		-0.020
		(0.131)
2011		-0.059
		(0.136)
R-square	0.010	0.019
N	2885	2885

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.9: RQ1 first round of regressions for CO2 emissions per capita – basic model

Variables	OLS		Fixed Effects	
Constant	18.141	*	18.604	*
	(0.546)		(1.889)	
LRT Presence	9.215	*	9.373	*
	(2.402)		(2.400)	
CRT Presence	7.198		7.272	
	(5.165)		(5.162)	
HRT Presence	3.048		3.033	
	(8.663)		(8.653)	
LRT*CRT	14.733	*	14.530	*
	(7.217)		(7.209)	
LRT*HRT	1.594		1.437	
	(12.461)		(12.446)	
CRT*HRT	16.555		16.455	
	(11.211)		(11.197)	

Table B.9: (continued)

Variables	OLS	Fixed Effects	
LRT*CRT*HRT	-20.402	-20.159	
	(15.442)	(15.423)	
Years			
2001		0.020	
		(2.634)	
2002		6.485	*
		(2.629)	
2003		-0.565	
		(2.627)	
2004		-1.106	
		(2.617)	
2005		-1.856	
		(2.611)	
2006		-2.119	
		(2.611)	
2007		-2.442	
		(2.611)	
2008		-2.946	
		(2.613)	
2009		-0.413	
		(2.484)	
2010		-0.958	
		(2.481)	
2011		0.522	
		(2.572)	
R-square	0.047	0.052	
N	3381	3381	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05

Year 2000 is omitted, naturally coded.

Table B.10: RQ1 first round of regressions for CO2 emissions per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	9.724		11.295	
	(0.788)		(1.207)	
LRT Presence	0.989		1.106	
	(1.248)		(1.246)	
CRT Presence	3.230		3.262	
	(2.336)		(2.330)	
HRT Presence	-1.503		-1.524	
	(3.861)		(3.849)	
LRT*CRT	4.899		4.571	
	(3.320)		(3.311)	
LRT*HRT	8.394		8.211	
	(5.514)		(5.498)	
CRT*HRT	-6.590		-6.832	
	(5.077)		(5.064)	
LRT*CRT*HRT	-6.729		-6.060	
	(6.987)		(6.968)	
Population Density	0.001		0.001	
	-4.92E-04		(4.92E-04)	
Housing Density	4.59E-04	*	4.52E-04	*
	(1.26E-04)		(1.27E-04)	
Employment Density	0.652	*	0.066	*
	(0.011)		(0.011)	
Ridership	-6.37E-08	*	-6.72E-08	*
	(8.01E-09)		(8.12E-09)	
Directional Route Miles	-3.13E-04		-3.38E-04	
	(4.13E-04)		(4.12E-04)	
Operating Expenses	-1.84E-09		-3.56E-10	
	(3.39E-09)		(3.44E-09)	
Vehicles at Max Service	0.015	*	0.015	*
	(0.001)		(0.001)	
Years				
2001			0.002	
			-1.275	
2002			0.865	
			(1.282)	
2003			-1.037	
			(1.245)	
2004			-1.719	
			(1.240)	
2005			-2.478	*
			(1.237)	

Table B.10: (continued)

Variables	OLS		Fixed Effects	
2006			-2.711	*
			(1.242)	
2007			-3.044	*
			(1.242)	
2008			-3.565	*
			(1.243)	
2009			-0.830	
			(1.204)	
2010			-1.294	
			(1.204)	
2011			-0.202	
			(1.247)	
R-square	0.310		0.317	
N	2911		2911	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Second Round Regressions

Table B.11: RQ1 second round of regressions for air quality index – basic model

Variables	OLS		Fixed Effects	
Constant	39.793	*	42.306	*
	(0.197)		(0.645)	
LRT Presence	15.296	*	15.362	*
	(1.002)		(0.994)	
CRT Presence	2.268		2.774	
	(2.124)		(2.108)	
HRT Presence	18.624	*	18.643	*
	(3.513)		(3.484)	
LRT*CRT	-7.245	*	-7.348	*
	(2.959)		(2.935)	
LRT*HRT	-8.171		-8.237	
	(5.061)		(5.019)	
CRT*HRT	-6.279		-6.734	
	(4.561)		(4.523)	

Table B.11: (continued)

Variables	OLS		Fixed Effects	
LRT*CRT*HRT	3.045		3.064	
	(6.313)		(6.262)	
Years				
2001			-0.648	
			(0.910)	
2002			-1.275	
			(0.911)	
2003			-1.780	
			(0.911)	
2004			-3.001	*
			(0.914)	
2005			-1.499	
			(0.914)	
2006			-2.321	*
			(0.915)	
2007			-1.696	
			(0.916)	
2008			-3.465	*
			(0.916)	
2009			-5.936	*
			(0.913)	
2010			-4.325	*
			(0.914)	
2011			-4.440	*
			(0.913)	
R-square	0.107		0.124	
N	4152		4152	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05

Year 2000 is omitted, naturally coded.

Table B.12: RQ1 second round of regressions for air quality index – expanded model

Variables	OLS		Fixed Effects	
Constant	37.847	*	42.161	*
	(0.670)		(1.017)	

Table B.12: (continued)

Variables	OLS		Fixed Effects	
LRT Presence	7.469	*	7.121	*
	(1.110)		(1.096)	
CRT Presence	-3.047		-2.563	
	(2.053)		(2.025)	
HRT Presence	7.766	*	7.733	*
	(3.499)		(3.451)	
LRT*CRT	-7.087	*	-7.652	*
	(2.912)		(2.872)	
LRT*HRT	4.186		3.699	
	(4.895)		(4.828)	
CRT*HRT	-11.197	*	-13.613	*
	(4.664)		(4.608)	
LRT*CRT*HRT	-0.880		1.216	
	(6.207)		(6.126)	
Population Density	1.92E-03	*	2.02E-03	*
	(3.93E-04)		(3.88E-04)	
Housing Density	4.06E-04	*	5.07E-04	*
	(1.04E-04)		(1.03E-04)	
Employment Density	-4.93E-02	*	-5.90E-02	*
	(8.17E-03)		(8.15E-03)	
Ridership	5.11E-08	*	3.03E-08	*
	(1.43E-08)		(1.43E-08)	
Directional Route Miles	3.92E-03	*	3.96E-03	*
	(3.72E-04)		(3.67E-04)	
Operating Expenses	-2.66E-08	*	-1.44E-08	*
	(5.62E-09)		(5.72E-09)	
Vehicles at Max Service	1.89E-03		5.30E-04	
	(1.50E-03)		(1.49E-03)	
Years				
2001			-0.907	
			(1.083)	
2002			-2.185	*
			(1.085)	
2003			-2.905	*
			(1.051)	
2004			-4.337	*
			(1.050)	
2005			-2.866	*
			(1.048)	
2006			-3.835	*
			(1.052)	
2007			-3.101	*
			(1.052)	

Table B.12: (continued)

Variables	OLS		Fixed Effects	
2008			-4.989	*
			(1.055)	
2009			-7.682	*
			(1.049)	
2010			-6.173	*
			(1.050)	
2011			-5.842	*
			(1.075)	
R-square	0.225		0.249	
N	2973		2973	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.13: RQ1 second round of regressions for energy intensity – basic model

Variables	OLS		Fixed Effects	
Constant	7954.477	*	6910.851	*
	(371.788)		(1295.629)	
LRT Presence	-4117.361	*	-4210.961	*
	(1695.510)		(1694.395)	
CRT Presence	-4749.247		-4577.523	*
	(3581.307)		(3578.309)	
HRT Presence	-5990.483		-6043.398	
	(5918.525)		(5911.885)	
LRT*CRT	4300.007		4321.205	
	(4986.629)		(4981.334)	
LRT*HRT	5928.916		6022.517	
	(8523.859)		(8514.272)	
CRT*HRT	18507.560	*	18368.590	
	(7683.253)		(7674.866)	
LRT*CRT*HRT	-19606.180		-19680.680	
	(10632.980)		(10621.160)	
Years				
2001			2099.424	
			(1808.575)	

Table B.13: (continued)

Variables	OLS		Fixed Effects	
2002			522.691	
			(1810.288)	
2003			937.123	
			(1806.874)	
2004			3760.883	*
			(1822.725)	
2005			4781.242	*
			(1792.104)	
2006			383.517	
			(1785.838)	
2007			-35.274	
			(1778.143)	
2008			-388.087	
			(1775.152)	
2009			527.170	
			(1695.891)	
2010			685.206	
			(1690.891)	
2011			-115.407	
			(1751.322)	
R-square	0.006		0.012	
N	3380		3380	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.14: RQ1 second round of regressions for energy intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	10526.470	*	9945.533	*
	(1174.322)		(1800.643)	
LRT Presence	-1507.794		-1702.581	
	(1876.548)		(1875.733)	
CRT Presence	-2468.993		-2258.278	
	(3457.228)		(3451.556)	

Table B.14: (continued)

Variables	OLS		Fixed Effects	
HRT Presence	-8484.539		-8565.496	
	(5891.273)		(5879.204)	
LRT*CRT	6022.474		5976.822	
	(4906.543)		(4898.408)	
LRT*HRT	6427.271		6461.724	
	(8239.276)		(8222.835)	
CRT*HRT	17315.160	*	16548.660	*
	(7850.705)		(7847.949)	
LRT*CRT*HRT	-25795.220	*	-25522.790	*
	(10448.960)		(10435.600)	
Population Density	-1.727	*	-1.626	*
	(0.728)		(0.728)	
Housing Density	-0.124		-0.093	
	(0.186)		(0.187)	
Employment Density	16.270		12.336	
	(16.463)		(16.587)	
Ridership	4.28E-05		3.90E-05	
	(2.41E-05)		(2.44E-05)	
Directional Route Miles	0.312		0.319	
	(0.625)		(0.624)	
Operating Expenses	1.51E-05		1.82E-05	
	(9.48E-06)		(9.76E-06)	
Vehicles at Max Service	-8.867	*	-9.367	*
	(2.536)		(2.547)	
Years				
2001			-25.675	
			(1894.051)	
2002			584.532	
			(1904.964)	
2003			734.294	
			(1849.327)	
2004			3881.642	*
			(1861.553)	
2005			4964.554	*
			(1836.924)	
2006			-120.246	
			(1833.267)	
2007			-593.759	
			(1829.657)	
2008			-758.937	
			(1830.106)	

Table B.14: (continued)

Variables	OLS	Fixed Effects
2009		10.930
		(1779.426)
2010		147.258
		(1780.255)
2011		-513.662
		(1842.256)
R-square	0.015	0.023
N	2934	2934

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.15: RQ1 second round of regressions for energy consumption per capita – basic model

Variables	OLS		Fixed Effects	
Constant	267237.200	*	258425.700	*
	(7377.902)		(25905.460)	
LRT Presence	169995.300	*	172588.800	*
	(33883.380)		(33864.730)	
CRT Presence	114446.700		112183.700	
	(70539.760)		(70504.360)	
HRT Presence	158894.500		159436.600	
	(118315.100)		(118203.200)	
LRT*CRT	243413.800	*	241275.300	*
	(98933.900)		(98847.190)	
LRT*HRT	-61799.940		-64393.450	
	(170400.000)		(170238.200)	
CRT*HRT	297342.000		298865.000	
	(153108.700)		(152971.100)	
LRT*CRT*HRT	-316243.600		-312901.100	
	(212213.200)		(212012.400)	
Years				
2001			1135.171	
			(36128.040)	
2002			92892.080	*
			(36060.680)	

Table B.15: (continued)

Variables	OLS	Fixed Effects
2003		-4504.822
		(35994.160)
2004		-8362.115
		(35864.830)
2005		-13681.400
		(35674.340)
2006		-17596.700
		(35584.270)
2007		-14578.280
		(35434.290)
2008		-12018.450
		(35464.020)
2009		23179.250
		(33847.410)
2010		17120.780
		(33788.800)
2011		35647.710
		(34967.110)
R-square	0.078	0.083
N	3426	3426

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.16: RQ1 second round of regressions for energy consumption per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	132450.200	*	131988.000	*
	(10964.960)		(16819.770)	
LRT Presence	37442.680	*	41720.010	*
	(17562.880)		(17531.030)	
CRT Presence	52499.370		49730.430	
	(32359.390)		(32263.000)	
HRT Presence	104072.300		104173.100	
	(55141.490)		(54954.140)	
LRT*CRT	116094.300	*	114455.100	*
	(45923.980)		(45786.010)	

Table B.16: (continued)

Variables	OLS		Fixed Effects	
LRT*HRT	36589.960		35791.330	
	(77120.580)		(76862.880)	
CRT*HRT	-58940.990		-50535.790	
	(73482.120)		(73358.570)	
LRT*CRT*HRT	-76595.140		-78189.560	
	(97802.150)		(97545.850)	
Population Density	25.682	*	22.990	*
	(6.794)		(6.791)	
Housing Density	5.877	*	5.126	*
	(1.741)		(1.746)	
Employment Density	840.863	*	926.906	*
	(153.418)		(154.381)	
Ridership	-0.001	*	-0.001	*
	(2.26E-04)		(2.28E-04)	
Directional Route Miles	-11.965	*	-12.390	*
	(5.844)		(5.830)	
Operating Expenses	6.16E-05		2.32E-05	
	(8.87E-05)		(9.12E-05)	
Vehicles at Max Service	212.269	*	218.122	*
	(23.734)		(23.799)	
Years				
2001			936.611	
			(17684.130)	
2002			17432.030	
			(17785.370)	
2003			-8666.904	
			(17236.620)	
2004			-14189.040	
			(17165.420)	
2005			-18900.990	
			(17093.020)	
2006			-21992.900	
			(17121.010)	
2007			-19139.850	
			(17087.670)	
2008			-15786.560	
			(17106.830)	
2009			24956.640	
			(16632.960)	
2010			18429.570	
			(16640.580)	

Table B.16: (continued)

Variables	OLS	Fixed Effects
2011		31831.170
		(17219.970)
R-square	0.397	0.403
N	2960	2960

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.17: RQ1 second round of regressions for CO2 intensity – basic model

Variables	OLS		Fixed Effects	
Constant	0.555	*	0.496	*
	(0.028)		(0.095)	
LRT Presence	-0.304	*	-0.311	*
	(0.125)		(0.124)	
CRT Presence	-0.341		-0.324	
	(0.263)		(0.263)	
HRT Presence	-0.457		-0.461	
	(0.434)		(0.434)	
LRT*CRT	0.289		0.290	
	(0.366)		(0.366)	
LRT*HRT	0.433		-0.440	
	(0.626)		(0.625)	
CRT*HRT	0.975		0.960	
	(0.564)		(0.563)	
LRT*CRT*HRT	-1.029		-1.034	
	(0.780)		(0.779)	
Years				
2001			0.151	
			(0.133)	
2002			0.032	
			(0.133)	
2003			0.066	
			(0.133)	

Table B.17: (continued)

Variables	OLS		Fixed Effects	
2004			0.265	*
			(0.134)	
2005			0.341	*
			(0.132)	
2006			0.014	
			(0.132)	
2007			-0.021	
			(0.132)	
2008			-0.060	
			(0.132)	
2009			0.001	
			(0.125)	
2010			0.006	
			(0.125)	
2011			-0.045	
			(0.130)	
R-square	0.005		0.011	
N	3312		3312	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.18: RQ1 second round of regressions for CO2 intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	0.746	*	0.725	*
	(0.087)		(0.133)	
LRT Presence	-0.106		-0.123	
	(0.139)		(0.138)	
CRT Presence	-0.182		-0.163	
	(0.255)		(0.255)	
HRT Presence	-0.559		-0.563	
	(0.435)		(0.434)	
LRT*CRT	0.350		0.342	
	(0.362)		(0.362)	
LRT*HRT	0.415		0.413	
	(0.608)		(0.607)	

Table B.18: (continued)

Variables	OLS		Fixed Effects	
CRT*HRT	0.984		0.909	
	(0.579)		(0.579)	
LRT*CRT*HRT	-1.331		-1.295	
	(0.771)		(0.770)	
Population Density	-1.31E-04	*	-1.21E-04	*
	(5.39E-05)		(5.40E-05)	
Housing Density	-8.26E-06		-5.16E-06	
	(1.38E-05)		(1.38E-05)	
Employment Density	-1.22E-03		8.43E-04	
	(0.001)		(1.23E-03)	
Ridership	2.24E-09		1.81E-09	
	(1.78E-09)		(1.80E-09)	
Directional Route Miles	8.35E-07		1.43E-06	
	(4.61E-05)		(4.61E-05)	
Operating Expenses	6.78E-10		1.00E-09	
	(7.00E-10)		(7.21E-10)	
Vehicles at Max Service	-4.23E-04	*	-4.70E-04	*
	(1.87E-04)		(1.88E-04)	
Years				
2001			-0.004	
			(0.140)	
2002			0.034	
			(0.141)	
2003			0.050	
			(0.137)	
2004			0.270	*
			(0.138)	
2005			0.354	*
			(0.136)	
2006			-0.023	
			(0.136)	
2007			-0.062	
			(0.136)	
2008			-0.088	
			(0.136)	
2009			-0.038	
			(0.132)	
2010			-0.035	
			(0.132)	
2011			-0.075	
			(0.137)	

Table B.18: (continued)

Variables	OLS	Fixed Effects
R-square	0.011	0.020
N	2871	2871

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.19: RQ1 second round of regressions for CO_2 emissions per capita – basic model

Variables	OLS		Fixed Effects	
Constant	18.141	*	18.618	*
	(0.548)		(1.901)	
LRT Presence	9.757	*	9.920	*
	(2.489)		(2.487)	
CRT Presence	7.198		7.279	
	(5.179)		(5.175)	
HRT Presence	3.048		3.031	
	(8.686)		(8.675)	
LRT*CRT	14.191		13.980	
	(7.263)		(7.255)	
LRT*HRT	1.052		0.889	
	(12.509)		(12.494)	
CRT*HRT	16.555		16.449	
	(11.240)		11.227	
LRT*CRT*HRT	-23.266		-23.014	
	(15.579)		(15.560)	
Years				
2001			0.016	
			(2.651)	
2002			6.530	*
			(2.646)	
2003			-0.563	
			(2.644)	
2004			-1.119	
			(2.634)	
2005			-1.784	
			(2.627)	

Table B.19: (continued)

Variables	OLS	Fixed Effects
2006		-2.172
		(2.627)
2007		-2.463
		(2.627)
2008		-2.983
		(2.630)
2009		-0.455
		(2.499)
2010		-0.990
		(2.496)
2011		0.463
		(2.588)
R-square	0.040	0.046
N	3357	3357

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.20: RQ1 second round of regressions for CO_2 emissions per capita – expanded model

Variables	OLS		Fixed Effects
Constant	9.316	*	10.765
	(0.797)		(1.217)
LRT Presence	0.930		1.052
	(1.269)		(1.268)
CRT Presence	2.567		2.598
	(2.338)		(2.333)
HRT Presence	1.678		1.646
	(3.984)		(3.973)
LRT*CRT	4.622		4.245
	(3.319)		(3.311)
LRT*HRT	6.201		5.944
	(5.572)		(5.557)
CRT*HRT	-1.100		-1.643
	(5.309)		(5.304)
LRT*CRT*HRT	-3.918		-3.082
	(7.067)		(7.053)

Table B.20: (continued)

Variables	OLS		Fixed Effects	
Population Density	0.001		0.001	
	(4.93E-04)		(4.93E-04)	
Housing Density	4.47E-04	*	4.38E-04	*
	(1.26E-04)		(1.26E-04)	
Employment Density	0.068	*	6.95E-02	*
	(0.011)		(1.12E-02)	
Ridership	-9.28E-08	*	-9.79E-08	*
	(1.63E-08)		(1.65E-08)	
Directional Route Miles	-2.65E-04		-2.84E-04	
	(4.23E-04)		(4.22E-04)	
Operating Expenses	-1.34E-08	*	-1.04E-08	
	(6.41E-09)		(6.60E-09)	
Vehicles at Max Service	0.020	*	0.020	*
	(0.002)		(0.002)	
Years				
2001			(0.029)	
			-1.279	
2002			0.880	
			(1.286)	
2003			-0.947	
			(1.247)	
2004			-1.633	
			(1.242)	
2005			-2.243	
			(1.240)	
2006			-2.582	*
			(1.246)	
2007			-2.943	*
			(1.248)	
2008			-3.447	*
			(1.250)	
2009			-0.612	
			(1.210)	
2010			-1.130	
			(1.212)	
2011			0.005	
			(1.255)	
R-square	0.293		0.300	
N	2897		2897	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant

Table B.20: (continued)

variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Third Round Regressions

Table B.21: RQ1 third round of regressions for Air quality index – basic model

Variables	OLS		Fixed Effects	
Constant	39.768	*	42.314	*
	(0.196)		(0.639)	
LRT Presence	15.320	*	15.391	*
	(0.994)		(0.986)	
CRT Presence	2.292		2.796	
	(2.107)		(2.091)	
HRT Presence	18.648	*	18.667	*
	(3.485)		(3.455)	
LRT*CRT	-7.269	*	-7.376	*
	(2.936)		(2.911)	
LRT*HRT	-8.195		-8.266	
	(5.020)		(4.978)	
CRT*HRT	-6.304		-6.756	
	(4.525)		(4.487)	
LRT*CRT*HRT	3.542		3.570	
	(6.229)		(6.177)	
Years				
2001			-0.643	
			(0.901)	
2002			-1.282	
			(0.902)	
2003			-1.784	
			(0.902)	
2004			-3.007	*
			(0.905)	
2005			-1.510	
			(0.905)	
2006			-2.597	*
			(0.907)	
2007			-1.711	
			(0.907)	
2008			-3.471	*
			(0.908)	
2009			-5.951	*
			(0.904)	
2010			-4.353	*
			(0.905)	

Table B.21: (continued)

Variables	OLS		Fixed Effects	
2011			-4.461	*
			(0.904)	
R-square	0.114		0.131	
N	4163		4163	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.22: RQ1 third round of regressions for Air quality index – expanded model

Variables	OLS		Fixed Effects	
Constant	37.677	*	42.252	*
	(0.658)		(1.000)	
LRT Presence	7.183	*	6.992	*
	(1.097)		(1.080)	
CRT Presence	-3.234		-2.735	
	(2.035)		(2.003)	
HRT Presence	10.340	*	10.230	*
	(3.365)		(3.311)	
LRT*CRT	-7.268	*	-7.778	*
	(2.893)		(2.847)	
LRT*HRT	1.268		1.063	
	(4.810)		(4.733)	
CRT*HRT	-11.711	*	-12.997	*
	(4.426)		(4.357)	
LRT*CRT*HRT	3.204		4.593	
	(6.090)		(5.994)	
Population Density	2.03E-03	*	0.002	*
	(3.88E-04)		(3.82E-04)	
Housing Density	4.06E-04	*	5.10E-04	*
	(1.03E-04)		(1.02E-04)	
Employment Density	-4.99E-02	*	-5.96E-02	*
	(8.11E-03)		(8.06E-03)	
Ridership	-1.47E-09		-1.33E-08	
	(6.98E-09)		(6.97E-09)	

Table B.22: (continued)

Variables	OLS		Fixed Effects	
Directional Route Miles	4.11E-03	*	0.004	*
	(3.61E-04)		(3.56E-04)	
Operating Expenses	-5.94E-09	*	-6.34E-10	
	(2.95E-09)		(2.95E-09)	
Vehicles at Max Service	-1.91E-04		-4.17E-04	
	(1.11E-03)		(1.09E-03)	
Years				
2001			-0.924	
			(1.072)	
2002			-2.349	*
			(1.074)	
2003			-3.048	*
			(1.040)	
2004			-4.503	*
			(1.039)	
2005			-3.060	*
			(1.037)	
2006			-4.363	*
			(1.041)	
2007			-3.375	*
			(1.038)	
2008			-5.262	*
			(1.041)	
2009			-8.005	*
			(1.035)	
2010			-6.548	*
			(1.035)	
2011			-6.228	*
			(1.059)	
R-square	0.225		0.252	
N	2983		2983	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05

Year 2000 is omitted, naturally coded.

Table B.23: RQ1 third round of regressions for energy intensity – basic model

Variables	OLS		Fixed Effects	
Constant	7692.739	*	6894.451	*
	(274.370)		(952.719)	
LRT Presence	-3714.259	*	-3777.576	*
	(1210.450)		(1209.949)	
CRT Presence	-4487.509		-4372.512	
	(2642.482)		(2640.724)	
HRT Presence	-5728.746		-5770.721	
	(4367.002)		(4362.875)	
LRT*CRT	3896.905		3905.765	
	(3665.797)		(3662.549)	
LRT*HRT	-5525.815		5589.132	
	(6281.405)		(6275.458)	
CRT*HRT	18245.820	*	18157.020	*
	(5669.111)		(5663.920)	
LRT*CRT*HRT	-19345.230	*	-19393.940	*
	(7797.442)		(7790.164)	
Years				
2001			2081.672	
			(1329.501)	
2002			519.703	
			(1330.751)	
2003			926.009	
			(1328.260)	
2004			3723.239	*
			(1339.817)	
2005			1803.800	
			(1318.648)	
2006			396.144	
			(1314.042)	
2007			-45.129	
			(1307.285)	
2008			-393.486	
			(1305.101)	
2009			521.795	
			(1247.163)	
2010			678.462	
			(1243.504)	
2011			-129.040	
			(1287.730)	
R-square	0.011		0.016	
N	3402		3402	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant

Table B.23: (continued)

variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.24: RQ1 third round of regressions for energy intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	9667.907	*	9194.244	*
	(750.664)		(1153.070)	
LRT Presence	-1450.665		-1524.430	
	(1192.280)		(1190.825)	
CRT Presence	-3081.763		-2964.880	
	(2229.984)		(2225.563)	
HRT Presence	-4953.795		-4952.418	
	(3685.915)		(3677.306)	
LRT*CRT	5760.457		5758.913	
	(3169.571)		(3162.852)	
LRT*HRT	3899.155		3908.427	
	(5264.614)		(5252.296)	
CRT*HRT	23044.740	*	22899.620	*
	(4846.716)		(4837.017)	
LRT*CRT*HRT	-23047.130	*	-23009.380	*
	(6670.729)		(6656.872)	
Population Density	-1.349	*	-1.292	*
	(0.468)		(0.469)	
Housing Density	-0.085		-0.068	
	(0.120)		(0.121)	
Employment Density	10.084		7.856	
	(10.622)		(10.689)	
Ridership	1.31E-05		1.20E-05	
	(7.65E-06)		(7.75E-06)	
Directional Route Miles	0.545		0.543	
	(0.394)		(0.394)	
Operating Expenses	3.03E-06		0.000	
	(3.24E-06)		(3.29E-06)	
Vehicles at Max Service	-4.503	*	-4.603	*
	(1.219)		(1.215)	
Years				
2001			-33.121	
			(1219.668)	
2002			570.572	
			(1226.605)	
2003			767.408	
			(1191.788)	

Table B.24: (continued)

Variables	OLS		Fixed Effects	
2004			3913.087	*
			(119.574)	
2005			1808.940	
			(1184.289)	
2006			59.748	
			(1181.154)	
2007			-383.077	
			(1175.834)	
2008			-529.288	
			(1175.696)	
2009			261.751	
			(1142.680)	
2010			359.844	
			(1142.386)	
2011			-281.811	
			(1181.369)	
R-square	0.028		0.036	
N	2946		2946	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.25: RQ1 third round of regressions for energy consumption per capita – basic model

Variables	OLS		Fixed Effects	
Constant	260444.100	*	257383.000	*
	(3560.743)		(12440.050)	
LRT Presence	166856.000	*	169198.200	*
	(15816.960)		(15792.010)	
CRT Presence	121239.800	*	117454.400	*
	(34033.130)		(33978.780)	
HRT Presence	165687.600	*	166771.200	*
	(57083.060)		(56966.980)	

Table B.25: (continued)

Variables	OLS		Fixed Effects	
LRT*CRT	246553.000	*	245328.500	*
	(47553.100)		(47459.280)	
LRT*HRT	-58660.640		-61002.820	
	(82108.280)		(81941.150)	
CRT*HRT	290548.900	*	293392.900	*
	(73869.760)		(73722.950)	
LRT*CRT*HRT	-207053.800	*	-204397.400	*
	(101755.400)		(101548.500)	
Years				
2001			1216.290	
			(17343.910)	
2002			12893.120	
			(17327.800)	
2003			-4567.841	
			(17280.100)	
2004			-8204.168	
			(17218.400)	
2005			-14070.250	
			(17142.890)	
2006			-16139.850	
			(17099.150)	
2007			-14213.400	
			(17013.130)	
2008			-11482.910	
			(17027.310)	
2009			23882.120	
			(16255.550)	
2010			17610.750	
			(16227.540)	
2011			36806.640	*
			(16790.730)	
R-square	0.322		0.327	
N	3447		3447	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.26: RQ1 third round of regressions for energy consumption per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	132961.200	*	132222.800	*
	(10809.460)		(16615.920)	
LRT Presence	38854.330	*	42452.380	*
	(17208.040)		(17169.090)	
CRT Presence	53722.810		50914.570	
	(32187.570)		(32091.150)	
HRT Presence	93992.970		94611.610	
	(53202.820)		(53024.190)	
LRT*CRT	120506.300	*	118870.800	*
	(45748.710)		(45604.850)	
LRT*HRT	46023.540		44179.800	
	(75991.190)		(75735.720)	
CRT*HRT	-60421.910		-55611.620	
	(69955.610)		(69745.090)	
LRT*CRT*HRT	-97810.330		-96942.670	
	(96286.370)		(95988.030)	
Population Density	26.332	*	23.705	*
	(6.745)		(6.742)	
Housing Density	5.951	*	5.194	*
	(1.738)		(1.742)	
Employment Density	821.157	*	907.495	*
	(152.658)		(153.465)	
Ridership	-0.001	*	-0.001	*
	(1.10E-04)		(1.12E-04)	
Directional Route Miles	-11.801	*	-12.023	*
	(5.689)		(5.677)	
Operating Expenses	2.43E-05		0.000	
	(4.67E-05)		(4.74E-05)	
Vehicles at Max Service	206.337	*	208.347	*
	(17.560)		(17.511)	
Years				
2001			1322.548	
			(17566.830)	
2002			17334.950	
			(17666.060)	
2003			-9395.155	
			(17135.210)	
2004			-14593.260	
			(17062.320)	
2005			-20084.240	
			(16998.920)	

Table B.26: (continued)

Variables	OLS	Fixed Effects
2006		-20402.500
		(17016.290)
2007		-18210.440
		(16940.270)
2008		-14781.390
		(16952.970)
2009		24853.450
		(16476.780)
2010		18785.750
		(16472.420)
2011		32120.240
		(17034.410)
R-square	0.452	0.458
N	2972	2972

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.27: RQ1 third round of regressions for CO_2 intensity – basic model

Variables	OLS		Fixed Effects	
Constant	0.535	*	0.495	*
	(0.020)		(0.069)	
LRT Presence	-0.274	*	-0.278	*
	(0.088)		(0.088)	
CRT Presence	-0.321		-0.308	
	(0.193)		(0.193)	
HRT Presence	-0.438		-0.441	
	(0.319)		(0.318)	
LRT*CRT	-0.259		0.259	
	(0.268)		(0.267)	
LRT*HRT	0.403		-0.407	
	(0.458)		(0.458)	
CRT*HRT	0.955	*	0.945	*
	(0.414)		(0.413)	

Table B.27: (continued)

Variables	OLS		Fixed Effects	
LRT*CRT*HRT	-1.009		-1.013	
	(0.569)		(0.568)	
Years				
2001			0.150	
			(0.097)	
2002			0.032	
			(0.097)	
2003			0.066	
			(0.097)	
2004			0.262	*
			(0.098)	
2005			0.120	
			(0.097)	
2006			0.015	
			(0.096)	
2007			-0.022	
			(0.096)	
2008			-0.060	
			(0.096)	
2009			0.001	
			(0.092)	
2010			0.006	
			(0.091)	
2011			-0.045	
			(0.095)	
R-square	0.009		0.015	
N	3334		3334	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.28: RQ1 third round of regressions for CO2 intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	0.693	*	0.683	*
	(0.055)		(0.085)	
LRT Presence	-0.105		-0.113	
	(0.088)		(0.087)	

Table B.28: (continued)

Variables	OLS		Fixed Effects	
CRT Presence	-0.211		-0.197	
	(0.164)		(0.163)	
HRT Presence	-0.384		-0.384	
	(0.271)		(0.270)	
LRT*CRT	0.330		0.326	
	(0.233)		(0.232)	
LRT*HRT	0.290		0.289	
	(0.387)		(0.386)	
CRT*HRT	1.244	*	1.223	*
	(0.356)		(0.355)	
LRT*CRT*HRT	-1.183		-1.170	*
	(0.490)		(0.489)	
Population Density	-1.05E-04	*	-9.90E-05	*
	(3.46E-05)		(3.46E-05)	
Housing Density	-5.18E-06		-3.00E-06	
	(8.86E-06)		(8.88E-06)	
Employment Density	7.24E-04		4.69E-04	
	(0.001)		(7.90E-04)	
Ridership	7.29E-10		5.54E-10	
	(5.62E-10)		(5.69E-10)	
Directional Route Miles	1.61E-05		1.56E-05	
	(2.90E-05)		(2.89E-05)	
Operating Expenses	1.25E-10		2.16E-10	
	(2.38E-10)		(2.42E-10)	
Vehicles at Max Service	-2.16E-04	*	-2.26E-04	*
	(8.94E-05)		(8.92E-05)	
Years				
2001			-0.005	
			(0.090)	
2002			0.033	
			(0.090)	
2003			0.052	
			(0.088)	
2004			-0.272	*
			(0.088)	
2005			0.117	
			(0.087)	
2006			-0.013	
			(0.087)	
2007			-0.051	
			(0.087)	

Table B.28: (continued)

Variables	OLS	Fixed Effects
2008		-0.076
		(0.087)
2009		-0.025
		(0.084)
2010		-0.024
		(0.084)
2011		-0.063
		(0.087)
R-square	0.021	0.031
N	2883	2883

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.29: RQ1 third round of regressions for CO_2 emissions per capita – basic model

Variables	OLS		Fixed Effects	
Constant	17.632	*	18.550	*
	(0.254)		(0.879)	
LRT Presence	9.724	*	9.849	*
	(1.118)		(1.116)	
CRT Presence	7.707	*	7.665	*
	(2.404)		(2.401)	
HRT Presence	3.557		3.568	
	(4.031)		(4.025)	
LRT*CRT	14.224	*	14.099	*
	(3.358)		(3.353)	
LRT*HRT	1.085		0.960	
	(5.798)		(5.789)	
CRT*HRT	16.046	*	16.049	*
	(5.217)		(5.209)	
LRT*CRT*HRT	-19.893	*	-19.708	*
	(7.186)		(7.174)	
Years				
2001			0.022	
			(1.225)	
2002			0.682	
			(1.224)	

Table B.29: (continued)

Variables	OLS	Fixed Effects	
2003		-0.565	
		(1.222)	
2004		-1.107	
		(1.218)	
2005		-1.885	
		(1.215)	
2006		-2.066	
		(1.215)	
2007		-2.444	*
		(1.214)	
2008		-2.951	*
		(1.215)	
2009		-0.408	
		(1.155)	
2010		-0.954	
		(1.154)	
2011		0.524	
		(1.196)	
R-square	0.190	0.196	
N	3378	3378	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Table B.30: RQ1 third round of regressions for CO2 emissions per capita – expanded model

Variables	OLS	Fixed Effects
Constant	9.695	11.258
	(0.788)	(1.207)
LRT Presence	0.898	1.017
	(1.248)	(1.246)
CRT Presence	3.172	3.208
	(2.334)	(2.329)

Table B.30: (continued)

Variables	OLS		Fixed Effects	
HRT Presence	-1.574		-1.592	
	(3.858)		(3.847)	
LRT*CRT	4.855		4.532	
	(3.318)		(3.309)	
LRT*HRT	8.484		8.298	
	(5.511)		(5.495)	
CRT*HRT	-6.712		-6.949	
	(5.074)		(5.061)	
LRT*CRT*HRT	-6.642		-5.982	
	(6.983)		(6.964)	
Population Density	0.001		0.001	
	(4.91E-04)		(4.91E-04)	
Housing Density	4.61E-04	*	4.54E-04	*
	(1.26E-04)		(1.27E-04)	
Employment Density	0.065	*	6.60E-02	*
	(0.011)		(1.12E-02)	
Ridership	6.41E-08	*	-6.76E-08	*
	(8.01E-09)		(8.11E-09)	
Directional Route Miles	-2.98E-04		-3.22E-04	
	(4.13E-04)		(4.12E-04)	
Operating Expenses	-1.89E-09		-4.06E-10	
	(3.39E-09)		(3.44E-09)	
Vehicles at Max Service	0.015	*	0.015	*
	(0.001)		(0.001)	
Years				
2001			0.001	
			(1.274)	
2002			0.862	
			(1.282)	
2003			-1.039	
			(1.244)	
2004			-1.719	
			(1.239)	
2005			-2.509	
			(1.238)	
2006			-2.589	
			(1.243)	
2007			-3.043	
			(1.241)	
2008			-3.562	
			(1.242)	

Table B.30: (continued)

Variables	OLS	Fixed Effects
2009		-0.830
		(1.203)
2010		-1.295
		(1.204)
2011		-0.206
		(1.246)
R-square	0.311	0.318
N	2909	2909

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded.

Research Question #2: For urban areas that have light rail transit systems, how to light rail, public transit, and urban area characteristics affect environmental sustainability indicators?

First Round Regressions

Table B.31: RQ2 first round of regressions for air quality index – basic model

Variables	OLS		Fixed Effects	
Constant	53.918	*	60.311	*
	(1.422)		(2.896)	
LRT Ridership	-4.20E-07	*	-5.65E-07	*
	(1.80E-07)		(1.73E-07)	
LRT DR Miles	-0.023		-0.029	
	(0.051)		(0.048)	
LRT Operating Expenses	-9.88E-08	*	5.22E-09	
	(4.99E-08)		(5.01E-08)	
LRT Veh at Max Service	0.080		0.081	
	(0.067)		(0.063)	
LRT Pass Miles Traveled	9.31E-08	*	1.05E-07	*
	(3.58E-08)		(3.40E-08)	
LRT Energy Consumption	3.08E-11		7.78E-12	
	(3.13E-11)		(2.99E-11)	
Years				
2001			0.699	
			(3.728)	
2002			-1.097	
			(3.737)	
2003			-2.856	
			(3.706)	
2004			-6.972	
			(3.642)	
2005			-5.187	
			(3.644)	
2006			-7.178	*
			(3.647)	
2007			-9.118	*
			(3.663)	
2008			-11.292	*
			(3.640)	

Table B.31: (continued)

Variables	OLS		Fixed Effects	
2009			-13.456	*
			(3.635)	
2010			-13.608	*
			(3.677)	
2011			-13.222	*
			(3.814)	
R-square	0.117		0.241	
N	279		279	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.32: RQ2 first round of regressions for air quality index – expanded model

Variables	OLS		Fixed Effects	
Constant	52.433	*	66.254	*
	(2.744)		(4.085)	
LRT Ridership	-2.41E-07		-5.51E-07	*
	(1.82E-07)		(1.80E-07)	
LRT DR Miles	0.070		2.41E-02	
	(0.065)		-6.21E-02	
LRT Operating Expenses	-7.22E-08		1.06E-07	
	(7.56E-08)		(7.78e-08)	
LRT Veh at Max Service	0.027		5.48E-02	
	(0.065)		-6.20E-02	
LRT Pass Miles Traveled	2.59E-08		6.51E-08	
	(3.65E-08)		(3.53e-08)	
LRT Energy Consumption	3.65E-11		-1.38E-12	
	(4.18E-11)		(4.03E-11)	
Population Density	-4.51E-04		-9.53E-05	
	(1.65E-03)		-1.62E-03	
Housing Density	3.67E-03		1.04E-04	
	(2.50E-03)		-2.45E-03	

Table B.32: (continued)

Variables	OLS		Fixed Effects	
Employment Density	-7.24E-02		-1.16E-01	*
	(4.63E-02)		-4.63E-02	
Ridership	1.46E-08		5.67-09	
	(9.54E-09)		(9.20e-09)	
Directional Route Miles	2.36E-03	*	2.49E-03	*
	(5.89E-04)		-5.75E-04	
Operating Expenses	-4.03E-09		-4.84E-10	
	(4.22E-09)		(4.06E-09)	
Vehicles at Max Service	-2.44E-03		-2.91E-03	
	(1.59E-03)		-1.54E-03	
Years				
2001			0.396	
			(3.409)	
2002			-3.650	
			(3.474)	
2003			-3.874	
			(3.471)	
2004			-6.506	
			(3.409)	
2005			-5.703	
			(3.458)	
2006			-7.562	*
			(3.479)	
2007			-9.537	*
			(3.519)	
2008			-12.076	*
			(3.541)	
2009			-14.633	*
			(3.592)	
2010			-15.222	*
			(3.712)	
2011			-15.588	*
			(3.967)	
R-square	0.295		0.392	
N	274		274	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.33: RQ2 first round of regressions for energy intensity – basic model

Variables	OLS		Fixed Effects	
Constant	4730.346	*	4484.238	*
	(128.390)		(281.859)	
LRT Ridership	-2.48E-05		-1.88E-05	
	(1.71E-05)		(1.74E-05)	
LRT DR Miles	-24.377	*	-23.941	*
	(4.816)		(4.832)	
LRT Operating Expenses	1.16E-06		-2.67E-06	
	(4.73E-06)		(5.02E-06)	
LRT Veh at Max Service	-6.770		-7.010	
	(6.315)		(6.357)	
LRT Pass Miles Traveled	2.67E-06		2.23E-06	
	(3.39E-06)		(3.41E-06)	
LRT Energy Consumption	4.46E-09		5.23E-09	
	(2.97E-09)		(3.00E-09)	
Years				
2001			-83.111	
			(369.899)	
2002			306.729	
			(370.727)	
2003			16.019	
			(363.555)	
2004			415.748	
			(357.563)	
2005			256.497	
			(357.702)	
2006			205.041	
			(358.040)	
2007			293.276	
			(359.469)	
2008			-24.452	
			(357.300)	
2009			635.375	
			(356.860)	
2010			590.239	
			(360.819)	
2011			540.998	
			(378.342)	
R-square	0.393		0.416	
N	288		288	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant

Table B.33: (continued)

variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions
is omitted because of collinearity.

Table B.34: RQ2 first round of regressions for energy intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	5585.807	*	5892.607	*
	(269.043)		(415.668)	
LRT Ridership	-5.47E-05	*	-5.97E-05	*
	(1.79E-05)		-1.87E-05	
LRT DR Miles	-26.638	*	-27.390	*
	(6.343)		(6.449)	
LRT Operating Expenses	1.84E-05	*	-2.15E-05	*
	(7.44E-06)		(8.09E-06)	
LRT Veh at Max Service	-2.911		-2.755	
	(6.385)		(6.460)	
LRT Pass Miles Traveled	7.29E-06	*	8.63E-06	*
	(3.59E-06)		(3.67E-06)	
LRT Energy Consumption	-4.92E-10		-1.01E-09	
	(4.11E-09)		(4.20E-09)	
Population Density	-0.121		-1.47E-01	
	(0.162)		(1.68E-01)	
Housing Density	-0.245		-3.29E-01	
	(0.245)		(0.26)	
Employment Density	-1.081		-6.61E-01	
	(4.548)		(4.82E+00)	
Ridership	1.34E-07		2.38E-08	
	(9.39E-07)		(9.58E-07)	
Directional Route Miles	-0.089		-8.28E-02	
	(0.058)		(5.98E-02)	
Operating Expenses	8.03E-08		1.54E-07	
	(4.15E-07)		(4.23E-07)	
Vehicles at Max Service	-0.064		-8.74E-02	
	(0.157)		(1.60E-01)	
Years				
2001			-142.459	
			(350.479)	
2002			195.447	
			(357.314)	

Table B.34: (continued)

Variables	OLS	Fixed Effects
2003		-258.059
		(356.977)
2004		29.640
		(350.284)
2005		-194.902
		(355.172)
2006		-296.560
		(357.327)
2007		-266.535
		(361.249)
2008		-703.211
		(363.204)
2009		-127.340
		(368.166)
2010		-288.950
		(380.408)
2011		-244.141
		(407.569)
R-square	0.455	0.474
N	275	275

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.35: RQ2 first round of regressions for energy consumption per capita – basic model

Variables	OLS		Fixed Effects	
Constant	497864.800	*	628537.800	*
	(39696.440)		(85866.530)	
LRT Ridership	0.002		-1.43E-04	
	(0.005)		(0.005)	
LRT DR Miles	153.349		74.016	
	(1488.993)		(1472.017)	
LRT Operating Expenses	-0.009	*	0.010	*
	(0.001)		(0.002)	

Table B.35: (continued)

Variables	OLS		Fixed Effects	
LRT Veh at Max Service	1948.557		2127.602	
	(1952.610)		(1936.518)	
LRT Pass Miles Traveled	-0.001		-0.001	
	(0.001)		(0.001)	
LRT Energy Consumption	-3.68E-06	*	-4.17E-06	*
	(9.18E-07)		(9.15E-07)	
Years				
2001			-13668.310	
			(112687.500)	
2002			92328.640	
			(112939.600)	
2003			-125284.700	
			(110754.700)	
2004			-154315.900	
			(108929.200)	
2005			-191109.600	
			(108971.700)	
2006			-187648.200	
			(109074.800)	
2007			-218576.600	*
			(109510.000)	
2008			-259964.700	*
			(108849.200)	
2009			-162295.500	
			(108715.100)	
2010			-219046.000	*
			(109921.200)	
2011			-144791.000	
			(115259.500)	
R-square	0.275		0.323	
N	288		288	

Source: Author's Calculations

Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.36: RQ2 first round of regressions for energy consumption per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	459720.600	*	623980.200	*
	(65377.050)		(96882.520)	
LRT Ridership	0.016	*	0.013	*
	(0.004)		(0.004)	
LRT DR Miles	-591.431		-401.034	
	(1541.341)		(1503.210)	
LRT Operating Expenses	-0.004	*	-0.003	
	(0.002)		(0.002)	
LRT Veh at Max Service	185.384		344.780	
	(1551.460)		(1505.682)	
LRT Pass Miles Traveled	-0.003	*	-0.003	*
	(0.001)		(0.001)	
LRT Energy Consumption	1.87E-04		0.000	
	(1.00E-06)		(9.79E-07)	
Population Density	-56.17		-96.268	*
	(39.344)		(39.240)	
Housing Density	-183.16	*	-210.608	*
	(59.650)		(59.470)	
Employment Density	2437.50	*	3469.700	*
	(1105.229)		(1123.203)	
Ridership	-1.07E-03	*	-0.001	*
	(2.28E-03)		(2.23E-04)	
Directional Route Miles	2.82		6.026	
	(14.070)		(13.946)	
Operating Expenses	-8.57E-06		-9.80E-06	
	(1.01E-04)		(9.86E-05)	
Vehicles at Max Service	278.46	*	278.019	*
	(38.125)		(37.385)	
Years				
2001			-16179.020	
			(81688.510)	
2002			97009.270	
			(83281.490)	
2003			-135468.100	
			(83203.040)	
2004			-177492.000	*
			(81643.070)	
2005			-212422.200	*
			(82782.420)	
2006			-215326.200	*
			(83284.600)	

Table B.36: (continued)

Variables	OLS		Fixed Effects	
2007			-210274.700	*
			(84198.830)	
2008			-243777.800	*
			(84654.310)	
2009			-130465.600	
			(85810.810)	
2010			-154516.700	
			(88664.160)	
2011			-93639.440	
			(94994.910)	
R-square	0.611		0.655	
N	275		275	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.37: RQ2 first round of regressions for CO2 intensity – basic model

Variables	OLS		Fixed Effects	
Constant	0.325	*	0.311	*
	(0.010)		(0.023)	
LRT Ridership	-1.94E-09		-1.67E-09	
	(1.36E-09)		(1.39E-09)	
LRT DR Miles	-0.002	*	-0.002	*
	(3.82E-04)		-3.88E-04	
LRT Operating Expenses	6.95E-11		-6.84E-11	
	(3.76E-10)		(4.03E-10)	
LRT Veh at Max Service	-4.50E-04		-4.86E-04	
	(0.001)		(0.001)	
LRT Pass Miles Traveled	2.91E-10		2.71E-10	
	(2.69E-10)		(2.73E-10)	
LRT Energy Consumption	2.09E-13		2.43E-13	
	(2.36E-13)		(2.41E-13)	

Table B.37: (continued)

Variables	OLS		Fixed Effects	
Years				
2001			-0.004	
			(0.030)	
2002			0.023	
			(0.030)	
2003			0.001	
			(0.029)	
2004			0.031	
			(0.029)	
2005			0.018	
			(0.029)	
2006			0.011	
			(0.029)	
2007			0.017	
			(0.029)	
2008			-0.007	
			(0.029)	
2009			0.028	
			(0.029)	
2010			0.027	
			(0.029)	
2011			0.021	
			(0.030)	
R-square	0.415		0.426	
N	288		288	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.38: RQ2 first round of regressions for CO2 intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	0.384	*	0.428	*
	(0.022)		(0.034)	
LRT Ridership	-4.09E-09	*	-5.00E-09	*
	(1.45E-09)		(1.51E-09)	

Table B.38: (continued)

Variables	OLS		Fixed Effects	
LRT DR Miles	-0.002	*	-0.003	*
	(0.001)		(0.001)	
LRT Operating Expenses	1.01E-09		1.55E-09	*
	(6.03E-10)		-6.53E-10	
LRT Veh at Max Service	-0.001		-3.52E-05	
	(0.001)		(0.001)	
LRT Pass Miles Traveled	6.95E-10	*	8.22E-10	*
	(2.91E-10)		-2.96E-10	
LRT Energy Consumption	-3.25E-14		-1.30E-13	
	(3.34E-13)		(3.39E-13)	
Population Density	-2.50E-06		-2.25E-06	
	(1.31E-05)		(1.36E-05)	
Housing Density	-2.80E-05		-4.04E-05	
	(1.99E-05)		(2.06E-05)	
Employment Density	-1.13E-04		-2.16E-04	
	(3.69E-04)		(3.89E-04)	
Ridership	-1.27E-11		-4.10E-11	
	(7.61E-11)		(7.74E-11)	
Directional Route Miles	-6.53E-06		-6.16E-06	
	(4.69E-06)		(4.83E-06)	
Operating Expenses	1.59E-11		2.91E-11	
	(3.37E-11)		(3.42E-11)	
Vehicles at Max Service	-4.51E-06		-6.64E-06	
	(1.27E-05)		(1.29E-05)	
Years				
2001			-0.009	
			(0.028)	
2002			0.013	
			(0.029)	
2003			-0.019	
			(0.029)	
2004			0.002	
			(0.028)	
2005			-0.018	
			(0.029)	
2006			-0.028	
			(0.288)	
2007			-0.028	
			(0.029)	
2008			-0.062	*
			(0.029)	

Table B.38: (continued)

Variables	OLS	Fixed Effects
2009		-0.036
		(0.030)
2010		-0.045
		(0.031)
2011		-0.047
		(0.033)
R-square	0.454	0.477
N	275	275

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>\|t\| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.39: RQ2 first round of regressions for CO2 emissions per capita – basic model

Variables	OLS		Fixed Effects	
Constant	34.905		41.792	*
	(2.758)		(5.999)	
LRT Ridership	1.37E-07		5.49E-09	
	(3.68E-07)		(3.70E-07)	
LRT DR Miles	-0.111		-0.114	
	(0.103)		(0.103)	
LRT Operating Expenses	3.56E-07	*	4.43E-07	*
	(1.02E-07)		(1.07E-07)	
LRT Veh at Max Service	0.087		0.095	
	(0.136)		(0.135)	
LRT Pass Miles Traveled	-4.20E-08		-2.65E-08	
	(7.29E-08)		(7.25E-08)	
LRT Energy Consumption	-1.38E-10	*	-1.68E-10	*
	(6.38E-11)		(6.39E-11)	
Years				
2001			-0.387	
			(7.873)	

Table B.39: (continued)

Variables	OLS		Fixed Effects	
2002			8.641	
			(7.890)	
2003			-6.488	
			(7.738)	
2004			-7.545	
			(7.610)	
2005			-10.836	
			(7.613)	
2006			-10.480	
			(7.620)	
2007			-12.490	
			(7.651)	
2008			-15.636	*
			(7.605)	
2009			-9.160	
			(7.595)	
2010			-11.262	
			(7.679)	
2011			-7.825	
			8.052	
R-square	0.119		0.168	
N	288		288	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.40: RQ2 first round of regressions for CO_2 emissions per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	33.270	*	48.137	*
	(5.061)		(7.534)	
LRT Ridership	9.05E-07	*	0.000	
	(3.36E-07)		(0.000)	

Table B.40: (continued)

Variables	OLS		Fixed Effects	
LRT DR Miles	-0.112		-0.114	
	(0.119)		(0.117)	
LRT Operating Expenses	-3.40E-07	*	0.000	
	(1.40E-07)		(0.000)	
LRT Veh at Max Service	-0.013		0.002	
	(0.120)		(0.117)	
LRT Pass Miles Traveled	-1.61E-07	*	0.000	
	(6.75E-08)		(0.000)	
LRT Energy Consumption	1.32E-10		0.000	
	(7.74E-11)		(0.000)	
Population Density	-0.003		-5.30E-03	
	(0.003)		(0.003)	
Housing Density	-0.013	*	-1.61E-02	*
	(0.005)		(0.005)	
Employment Density	0.129		-1.82E-01	*
	(0.086)		(0.087)	
Ridership	-8.63E-08	*	-9.11E-08	*
	(1.77E-08)		-1.74E-08	
Directional Route Miles	6.29E-04		8.35E-04	
	(0.001)		0.001	
Operating Expenses	3.080		4.25E-09	
	(7.81E-09)		7.67E-09	
Vehicles at Max Service	0.018	*	1.77E-02	*
	(0.003)		-2.91E-03	
Years				
2001			-1.172	
			(6.353)	
2002			6.916	
			(6.477)	
2003			-9.547	
			(6.471)	
2004			-11.941	
			(6.349)	
2005			-15.970	*
			(6.438)	
2006			-16.253	*
			(6.477)	
2007			-16.225	*
			(6.548)	
2008			-19.695	*
			(6.583)	

Table B.40: (continued)

Variables	OLS		Fixed Effects	
2009			-13.194	*
			(6.673)	
2010			-14.116	*
			(6.895)	
2011			-11.442	
			(7.388)	
R-square	0.429		0.487	
N	275		275	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Second Round Regressions

Table B.41: RQ2 second round of regressions for air quality index – basic model

Variables	OLS		Fixed Effects	
Constant	53.921	*	59.398	*
	(1.430)		(3.017)	
LRT Ridership	-2.84E-07		-4.76E-07	*
	(1.86E-07)		(1.86E-07)	
LRT DR Miles	-0.090		-0.081	
	(0.056)		(0.054)	
LRT Operating Expenses	-2.52E-07	*	-1.09E-07	
	(6.20E-08)		(6.67E-08)	
LRT Veh at Max Service	0.067		0.080	
	(0.068)		(0.066)	
LRT Pass Miles Traveled	7.65E-08	*	9.78E-08	*
	(3.70E-08)		(3.62E-08)	
LRT Energy Consumption	1.34E-10	*	7.62E-11	
	(3.99E-11)		(4.05E-11)	
Years				
2001			0.820	
			(3.852)	
2002			-0.482	
			(3.863)	

Table B.41: (continued)

Variables	OLS		Fixed Effects	
2003			-2.010	
			(0.384)	
2004			-5.993	
			(3.779)	
2005			-3.994	
			(3.779)	
2006			-6.067	
			(3.773)	
2007			-7.970	*
			(3.785)	
2008			-10.057	*
			(3.768)	
2009			-11.528	*
			(3.797)	
2010			-11.197	*
			(3.868)	
2011			-11.315	*
			(4.008)	
R-square	0.170		0.257	
N	267		267	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.42: RQ2 second round of regressions for air quality index – expanded model

Variables	OLS		Fixed Effects	
Constant	62.561	*	74.468	*
	(3.130)		(4.284)	
LRT Ridership	-6.25E-07	*	-8.58E-07	*
	(1.85E-07)		(1.84E-07)	
LRT DR Miles	0.122		0.081	
	(0.067)		(0.065)	
LRT Operating Expenses	1.12E-07		2.08E-07	*
	(9.23E-08)		(9.20E-08)	

Table B.42: (continued)

Variables	OLS		Fixed Effects	
LRT Veh at Max Service	0.003		0.025	
	(0.063)		(0.061)	
LRT Pass Miles Traveled	-3.56E-09		4.36E-08	
	(3.56E-08)		-3.54E-08	
LRT Energy Consumption	2.08E-12		-2.67E-11	
	(4.42E-11)		(4.34E-11)	
Population Density	-0.003		-0.002	
	(0.002)		(0.002)	
Housing Density	-0.001		-0.004	
	(0.003)		(0.003)	
Employment Density	-0.037		-0.075	
	(0.046)		(0.047)	
Ridership	1.57E-07	*	1.29E-07	*
	(2.31E-08)		(2.33E-08)	
Directional Route Miles	0.001	*	1.72E-03	*
	(5.88E-04)		(5.79E-04)	
Operating Expenses	5.05E-08	*	-3.23E-08	*
	(1.15E-08)		(1.18E-08)	
Vehicles at Max Service	0.001		1.56E-03	
	(0.002)		(2.38E-03)	
Years				
2001			0.751	
			(3.314)	
2002			-2.350	
			(3.365)	
2003			-3.582	
			(3.368)	
2004			-7.068	
			(3.295)	
2005			-6.049	
			(3.344)	
2006			-7.625	*
			(3.371)	
2007			-8.576	*
			(3.417)	
2008			-10.847	*
			(3.460)	
2009			-13.335	*
			(3.512)	
2010			-13.428	*
			(3.628)	

Table B.42: (continued)

Variables	OLS		Fixed Effects	
2011			-12.345	*
			(3.878)	
R-square	0.400		0.472	
N	263		263	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.43: RQ2 second round of regressions for energy intensity – basic model

Variables	OLS		Fixed Effects	
Constant	4667.829	*	4508.374	*
	(134.660)		(295.963)	
LRT Ridership	-3.41E-05		-2.82E-05	
	(1.75E-05)		(1.82E-05)	*
LRT DR Miles	-20.517	*	-20.415	
	(5.296)		(5.345)	
LRT Operating Expenses	1.06E-05		7.00E-06	
	(5.84E-06)		(6.55E-06)	
LRT Veh at Max Service	-5.191		-5.974	
	(6.393)		(6.493)	
LRT Pass Miles Traveled	3.42E-06		2.74E-06	
	(3.49E-06)		(3.55E-06)	
LRT Energy Consumption	1.29E-09		1.91E-10	
	(3.76E-09)		(3.97E-09)	
Years				
2001			7.209	
			(377.821)	
2002			381.976	
			(378.873)	
2003			-28.781	
			(376.567)	

Table B.43: (continued)

Variables	OLS	Fixed Effects
2004		302.929
		(370.562)
2005		138.455
		(370.639)
2006		75.086
		370.019
2007		169.629
		(371.272)
2008		-222.022
		(369.544)
2009		443.510
		(372.427)
2010		363.182
		(379.432)
2011		384.770
		(393.151)
R-square	0.364	0.382
N	267	267

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.44: RQ2 second round of regressions for energy intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	6138.476	*	6219.251	*
	(324.899)		(466.433)	
LRT Ridership	-7.94E-05	*	-7.87E-05	*
	(1.92E-05)		-2.00E-05	
LRT DR Miles	-26.519	*	-26.241	*
	(6.968)		(7.108)	
LRT Operating Expenses	3.03E-05	*	2.87E-05	*
	(9.58E-06)		1.00E-05	
LRT Veh at Max Service	-2.532		-3.406	
	(6.576)		(6.691)	

Table B.44: (continued)

Variables	OLS		Fixed Effects	
LRT Pass Miles Traveled	6.56E-06		6.66E-06	
	(3.70E-06)		-3.85E-06	
LRT Energy Consumption	-1.79E-09		-1.22E-09	
	(4.59E-09)		-4.73E-09	
Population Density	-0.205		-0.247	
	(0.177)		(0.183)	
Housing Density	-0.563	*	-0.615	*
	(0.269)		(0.279)	
Employment Density	0.375		1.834	
	(4.807)		(5.103)	
Ridership	8.06E-06	*	8.02E-06	*
	(2.40E-06)		-2.54E-06	
Directional Route Miles	-1.33E-01	*	-0.132	*
	(0.061)		(0.063)	
Operating Expenses	-2.86E-06	*	-2.59E-06	*
	(1.19E-06)		-1.29E-06	
Vehicles at Max Service	0.208		0.148	
	(0.245)		(0.259)	
Years				
2001			-12.832	
			(360.833)	
2002			370.549	
			(366.378)	
2003			-81.356	
			(366.698)	
2004			73.610	
			(358.717)	
2005			-117.239	
			(364.085)	
2006			-176.693	
			(366.963)	
2007			-77.734	
			(372.018)	
2008			-476.113	
			(376.674)	
2009			132.764	
			(382.350)	
2010			-9.279	
			(395.022)	
2011			102.163	
			(422.199)	

Table B.44: (continued)

Variables	OLS	Fixed Effects
R-square	0.442	0.459
N	263	263

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.45: RQ2 second round of regressions for energy consumption per capita – basic model

Variables	OLS		Fixed Effects	
Constant	522986.300	*	591665.100	*
	(41034.810)		(89626.330)	
LRT Ridership	0.004		0.003	
	(0.005)		(0.006)	
LRT DR Miles	-3155.054		-3049.655	
	(1613.743)		(1618.745)	
LRT Operating Expenses	0.004	*	0.005	*
	(0.002)		(0.002)	
LRT Veh at Max Service	2340.161		2520.906	
	(1948.126)		(1966.243)	
LRT Pass Miles Traveled	-0.001		-0.001	
	(0.001)		(0.001)	
LRT Energy Consumption	-5.56E-07		-1.07E-06	
	(1.15E-06)		(1.20E-06)	
Years				
2001			-8875.420	
			(114415.400)	
2002			122346.900	
			(114734.000)	
2003			-79270.870	
			(114035.500)	
2004			-96978.910	
			(112217.200)	
2005			-122233.600	
			(112240.600)	

Table B.45: (continued)

Variables	OLS	Fixed Effects
2006		-117129.900
		(112052.800)
2007		-136494.100
		(112432.100)
2008		-170908.700
		(111908.800)
2009		-58547.940
		(112781.900)
2010		-99418.760
		(114903.100)
2011		-54470.210
		(119057.800)
R-square	0.207	0.240
N	267	267

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.46: RQ2 second round of regressions for energy consumption per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	395069.800	*	605406.300	*
	(79970.810)		(109181.100)	
LRT Ridership	0.021	*	0.018	*
	(0.005)		(0.005)	
LRT DR Miles	-253.065		-402.021	
	(1715.143)		(1663.833)	
LRT Operating Expenses	-0.007	*	-0.007	*
	(0.002)		(0.002)	
LRT Veh at Max Service	-674.127		-722.489	
	(1618.604)		(1566.268)	
LRT Pass Miles Traveled	-0.003	*	-0.003	*
	(0.001)		(0.001)	

Table B.46: (continued)

Variables	OLS		Fixed Effects	
LRT Energy Consumption	2.82E-06	*	2.63E-06	*
	'(1.13E-06)		-1.11E-06	
Population Density	-57.520		-86.558	*
	(43.463)		(42.856)	
Housing Density	-153.083	*	-206.677	*
	(66.170)		(65.221)	
Employment Density	2676.154	*	3391.020	*
	(1183.185)		(1194.542)	
Ridership	-0.002	*	-0.002	*
	(0.001)		(5.95E-04)	
Directional Route Miles	3.920		6.856	
	(15.011)		(14.752)	
Operating Expenses	4.05E-04		6.25E-04	*
	(2.94E-04)		(3.01E-04)	
Vehicles at Max Service	251.710	*	206.430	*
	-60.359		(60.567)	
Years				
2001			-31875.140	
			(84462.570)	
2002			100998.100	
			(85760.590)	
2003			-121342.400	
			(85835.490)	
2004			-160214.600	
			(83967.300)	
2005			-201431.300	*
			(85223.890)	
2006			-225372.100	*
			85897.520	
2007			-243346.200	*
			(87080.810)	
2008			-285666.700	*
			88170.610	
2009			-139922.100	
			89499.160	
2010			-162917.200	
			92465.410	
2011			-24395.300	
			(98826.960)	
R-square	0.544		0.600	
N	263		263	

Source: Author's Calculations

Table B.46: (continued)

Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.47: RQ2 second round of regressions for CO_2 intensity – basic model

Variables	OLS		Fixed Effects	
Constant	0.321	*	0.317	*
	(0.011)		(0.038)	
LRT Ridership	-2.67E-09		-2.61E-09	
	(1.40E-09)		(1.46E-09)	
LRT DR Miles	-0.002	*	-0.002	*
	(4.24E-04)		(4.30E-04)	
LRT Operating Expenses	7.36E-10		7.70E-10	
	(4.67E-10)		-5.27E-10	
LRT Veh at Max Service	-3.09E-04		(3.56E-04)	
	(0.001)		(0.001)	
LRT Pass Miles Traveled	3.62E-10		3.55E-10	
	(2.79E-10)		(2.86E-10)	
LRT Energy Consumption	-2.04E-13		-2.10E-13	
	(3.01E-13)		(3.19E-13)	
Years				
2001			0.001	
			(0.030)	
2002			0.026	
			(0.030)	
2003			-0.004	
			(0.030)	
2004			0.020	
			(0.030)	
2005			0.006	
			(0.030)	
2006			-0.003	
			(0.030)	
2007			0.004	
			(0.030)	
2008			-0.025	
			(0.030)	
2009			0.007	
			0.030	
2010			0.004	
			(0.031)	

Table B.47: (continued)

Variables	OLS		Fixed Effects	
2011			0.004	
			(0.032)	
R-square	0.388		0.398	
N	267		267	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>\|t\| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.48: RQ2 second round of regressions for CO2 intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	0.429	*	0.456	*
	(0.026)		(0.038)	
LRT Ridership	-6.10E-09	*	-6.47E-09	*
	(1.56E-09)		(1.63e-09)	
LRT DR Miles	-0.002	*	-0.002	*
	(0.001)		(0.001)	
LRT Operating Expenses	2.03E-09	*	2.10E-09	*
	(7.78E-10)		(8.13e-10)	
LRT Veh at Max Service	-4.84E-05		-7.64E-05	
	(0.001)		(0.001)	
LRT Pass Miles Traveled	5.70E-10		6.87E-10	*
	(3.00E-10)		(3.13e-10)	
LRT Energy Consumption	-1.30E-13		-1.39E-13	
	(3.73E-13)		(3.84e-13)	
Population Density	-8.97E-06		-9.00E-06	
	(1.43E-05)		(1.49E-05)	
Housing Density	-5.39E-05	*	-6.30E-05	*
	(2.18E-05)		(4.15E-04)	
Employment Density	-1.30E-07		-4.70E-05	
	(3.90E-04)		(4.15E-04)	
Ridership	6.42E-10	*	5.58E-10	*
	(1.95E-10)		(2.06E-10)	

Table B.48: (continued)

Variables	OLS		Fixed Effects
Directional Route Miles	-1.04E-05	*	-9.93E-06
	(4.95E-06)		(5.12e-06)
Operating Expenses	-2.41E-10	*	-1.75E-10
	(9.69E-11)		(1.04e-10)
Vehicles at Max Service	2.14E-05		1.07E-05
	(1.99E-05)		(2.10E-05)
Years			
2001			-0.002
			(0.029)
2002			0.024
			(0.029)
2003			-0.008
			(0.030)
2004			0.003
			(0.029)
2005			-0.014
			(0.030)
2006			-0.023
			(0.030)
2007			-0.017
			(0.030)
2008			-0.047
			(0.031)
2009			-0.019
			(0.031)
2010			-0.027
			(0.032)
2011			-0.023
			(0.034)
R-square	0.448		0.464
N	263		263

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.49: RQ2 second round of regressions for CO2 emissions per capita – basic model

Variables	OLS		Fixed Effects	
Constant	36.789	*	42.081	*
	(2.997)		(6.537)	
LRT Ridership	2.07E-07		7.22E-08	
	(3.90E-07)		(4.02E-07)	
LRT DR Miles	-0.251	*	-0.241	*
	(0.118)		(0.118)	
LRT Operating Expenses	1.67E-07		2.69E-07	
	(1.30E-07)		(1.45E-07)	
LRT Veh at Max Service	0.104		0.114	
	(0.142)		(0.143)	
LRT Pass Miles Traveled	-2.95E-08		-1.35E-08	
	(7.76E-08)		(7.85E-08)	
LRT Energy Consumption	-2.68E-11		-7.17E-11	
	(8.37E-11)		(8.77E-11)	
Years				
2001			-0.680	
			(8.346)	
2002			9.498	
			(8.369)	
2003			-5.108	
			(8.318)	
2004			-6.176	
			(8.185)	
2005			-8.293	
			(8.187)	
2006			-8.855	
			(8.173)	
2007			-10.174	
			(8.201)	
2008			-13.272	
			(8.163)	
2009			-6.365	
			(8.226)	
2010			-7.907	
			(8.381)	
2011			-5.792	
			(8.684)	
R-square	0.101		0.139	
N	267		267	

Table B.49: (continued)

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.50: RQ2 second round of regressions for CO2 emissions per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	27.801	*	44.963	*
	(6.195)		(8.522)	
LRT Ridership	1.27E-06	*	1.03E-06	*
	(3.67E-07)		(3.66e-07)	
LRT DR Miles	-0.081		-0.107	
	(0.133)		(0.130)	
LRT Operating Expenses	-4.76E-07	*	-4.11E-07	
	(1.83E-07)		(1.83e-07)	
LRT Veh at Max Service	-0.066		-0.067	
	(0.125)		(0.122)	
LRT Pass Miles Traveled	-1.92E-07	*	-1.43E-07	*
	(7.06E-08)		(7.04e-08)	
LRT Energy Consumption	1.85E-10	*	1.68E-10	
	(8.75E-11)		(8.64e-11)	
Population Density	-0.003		-4.77E-03	
	(0.003)		(0.003)	
Housing Density	-0.010	*	-0.015	*
	(0.005)		(0.005)	
Employment Density	0.152		0.181	
	(0.092)		(0.093)	
Ridership	-1.42E-07	*	-1.63E-07	*
	(4.58E-08)		(4.64e-08)	
Directional Route Miles	6.47E-04		8.82E-04	
	(0.012)		(0.001)	
Operating Expenses	1.50E-08		3.70E-08	
	(2.28E-08)		(2.35e-08)	
Vehicles at Max Service	0.019	*	1.52E-02	*
	(0.005)		(0.005)	
Years				
2001			-2.400	
			(6.593)	

Table B.50: (continued)

Variables	OLS		Fixed Effects	
2002			7.306	
			(6.694)	
2003			-8.532	
			(6.700)	
2004			-10.940	
			(6.554)	
2005			-14.303	*
			(6.652)	
2006			-16.730	*
			(6.705)	
2007			-18.089	*
			(6.797)	
2008			-21.917	*
			(6.882)	
2009			-13.226	
			(6.986)	
2010			-14.128	
			(7.273)	
2011			-13.005	
			(7.714)	
R-square	0.422		0.485	
N	263		263	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Third Round Regressions

Table B.51: RQ2 third round of regressions for air quality index – basic model

Variables	OLS		Fixed Effects	
Constant	53.918	*	60.311	*
	(1.422)		(2.896)	
LRT Ridership	-4.20E-07	*	-5.65E-07	*
	(1.80E-07)		(1.73E-07)	
LRT DR Miles	-0.023		-0.029	
	(0.051)		(0.048)	

Table B.51: (continued)

Variables	OLS		Fixed Effects	
LRT Operating Expenses	-9.88E-08	*	5.22E-09	
	(4.99E-08)		(5.01E-08)	
LRT Veh at Max Service	0.080		0.081	
	(0.067)		(0.063)	
LRT Pass Miles Traveled	9.31E-08	*	1.05E-07	*
	(3.58E-08)		(3.40E-08)	
LRT Energy Consumption	3.08E-11		7.78E-12	
	(3.13E-11)		(2.99E-11)	
Years				
2001			0.699	
			(3.728)	
2002			-1.097	
			(3.737)	
2003			-2.856	
			(3.706)	
2004			-6.972	
			(3.642)	
2005			-5.187	
			(3.644)	
2006			-7.178	*
			(3.647)	
2007			-9.118	*
			(3.663)	
2008			-11.292	*
			(3.640)	
2009			-13.456	*
			(3.635)	
2010			-13.608	*
			(3.677)	
2011			-13.222	*
			(3.814)	
R-square	0.117		0.241	
N	279		279	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.52: RQ2 third round of regressions for air quality index – expanded model

Variables	OLS		Fixed Effects	
Constant	52.433	*	66.254	*
	(2.744)		(4.085)	
LRT Ridership	-2.41E-07		-5.51E-07	*
	(1.82E-07)		(1.80E-07)	
LRT DR Miles	0.070		0.024	
	(0.065)		(0.062)	
LRT Operating Expenses	-7.22E-08		1.06E-07	
	(7.56E-08)		(7.78E-08)	
LRT Veh at Max Service	0.027		0.055	
	(0.065)		(0.062)	
LRT Pass Miles Traveled	2.59E-08		6.51E-08	
	(3.65E-08)		(3.53E-08)	
LRT Energy Consumption	3.65E-11		-1.38E-12	
	(4.18E-11)		(4.03E-11)	
Population Density	-4.51E-04		-9.53E-05	
	(0.002)		(1.62E-03)	
Housing Density	0.004		1.04E-04	
	(0.002)		(2.45E-03)	
Employment Density	-0.072		-1.16E-01	*
	(0.046)		(4.63E-02)	
Ridership	1.46E-08		5.67E-09	
	(9.54E-09)		(9.20E-09)	
Directional Route Miles	0.002	*	2.49E-03	*
	(5.89E-04)		(5.75E-04)	
Operating Expenses	-4.03E-09		-4.84E-10	
	(4.22E-09)		(4.06E-09)	
Vehicles at Max Service	-0.002		-2.49E-03	
	(0.002)		(1.54E-03)	
Years				
2001			0.396	
			(3.409)	
2002			-3.650	
			(3.474)	
2003			-3.874	
			(3.471)	
2004			-6.506	
			(3.409)	
2005			-5.703	
			(3.458)	
2006			-7.562	*
			3.479	

Table B.52: (continued)

Variables	OLS		Fixed Effects	
2007			-9.537	*
			(3.519)	
2008			-12.076	*
			(3.541)	
2009			-14.633	*
			(3.592)	
2010			-15.222	*
			(3.712)	
2011			-15.588	*
			(3.967)	
R-square	0.295		0.392	
N	274		274	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.53: RQ2 third round of regressions for energy intensity – basic model

Variables	OLS		Fixed Effects	
Constant	4730.346	*	4484.238	
	(128.390)		(281.859)	
LRT Ridership	-2.48E-05		-1.88E-05	
	(1.71E-05)		-1.74E-05	
LRT DR Miles	-24.377	*	-23.941	*
	(4.816)		(4.832)	
LRT Operating Expenses	1.16E-06		-2.67E-06	
	(4.73E-06)		(5.02E-06)	
LRT Veh at Max Service	-6.770		-7.010	
	(6.315)		(6.357)	
LRT Pass Miles Traveled	2.67E-06		2.23E-06	
	(3.39E-06)		(3.41E-06)	
LRT Energy Consumption	4.46E-09		5.23E-09	
	(2.97E-09)		(3.00E-09)	

Table B.53: (continued)

Variables	OLS		Fixed Effects	
Years				
2001			-83.111	
			(369.899)	
2002			306.729	
			(370.727)	
2003			16.019	
			(363.555)	
2004			415.748	
			(357.563)	
2005			256.497	
			357.702	
2006			205.041	
			358.040	
2007			293.276	
			359.469	
2008			-24.452	
			(357.300)	
2009			635.375	
			(356.860)	
2010			590.239	
			(360.819)	
2011			540.998	
			(378.342)	
R-square	0.393		0.416	
N	288		288	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.54: RQ2 third round of regressions for energy intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	5585.807	*	5892.607	*
	(269.043)		(415.668)	

Table B.54: (continued)

Variables	OLS		Fixed Effects	
LRT Ridership	-5.47E-05	*	-5.97E-05	*
	(1.79E-05)		(1.87E-05)	
LRT DR Miles	-26.638	*	-27.390	*
	(6.343)		(6.449)	
LRT Operating Expenses	1.84E-05	*	2.15E-05	*
	(7.44E-06)		(8.09E-06)	
LRT Veh at Max Service	-2.911		-2.755	
	(6.385)		(6.460)	
LRT Pass Miles Traveled	7.92E-06	*	8.63E-06	*
	(3.59E-06)		(3.67E-06)	
LRT Energy Consumption	-4.92E-10		-1.01E-09	
	(4.11E-09)		(4.20E-09)	
Population Density	-0.121		-0.147	
	(0.162)		(0.168)	
Housing Density	-0.245		-0.329	
	(0.245)		(0.255)	
Employment Density	-1.081		-0.661	
	(4.548)		(4.819)	
Ridership	1.34E-07		2.38E-08	
	(9.39E-07)		(9.58E-07)	
Directional Route Miles	-0.089		-8.28E-02	
	(0.058)		(5.98E-02)	
Operating Expenses	8.03E-08		1.54E-07	
	(4.15E-07)		(4.23E-07)	
Vehicles at Max Service	-0.064		-8.74E-02	
	(0.157)		(0.160)	
Years				
2001			-142.459	
			(350.479)	
2002			195.447	
			(357.314)	
2003			-258.059	
			(356.977)	
2004			29.640	
			(350.284)	
2005			-194.902	
			(355.172)	
2006			-296.560	
			(357.327)	
2007			-266.535	
			(361.249)	

Table B.54: (continued)

Variables	OLS	Fixed Effects
2008		-703.211
		(490.544)
2009		-368.166
		(288.950)
2010		-380.408
		(244.141)
2011		-407.569
R-square	0.455	0.474
N	275	275

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.55: RQ2 third round of regressions for energy consumption per capita – basic model

Variables	OLS		Fixed Effects	
Constant	497864.800	*	628537.800	*
	(39696.440)		(85866.530)	
LRT Ridership	0.002		-1.43E-04	
	(0.005)		(0.005)	
LRT DR Miles	153.349		74.016	
	(1488.993)		(1472.017)	
LRT Operating Expenses	0.009	*	0.010	*
	(0.001)		(0.002)	
LRT Veh at Max Service	1948.557		2127.602	
	(1952.610)		(1936.518)	
LRT Pass Miles Traveled	-0.001		-0.001	
	(0.001)		(0.001)	
LRT Energy Consumption	-3.68E-07	*	-4.17E-06	*
	(9.18E-07)		(9.15E-07)	

Table B.55: (continued)

Variables	OLS		Fixed Effects	
Years				
2001			-13668.310	
			(112687.500)	
2002			92328.640	
			(112939.600)	
2003			-125284.700	
			(110754.700)	
2004			-154315.900	
			(108929.200)	
2005			-191109.600	
			(108971.700)	
2006			-187648.200	
			(109074.800)	
2007			-218576.600	
			(109510.000)	
2008			-259964.700	*
			(108849.200)	
2009			-162295.500	
			(108715.100)	
2010			-219046.000	*
			(109921.200)	
2011			-144791.000	
			(115259.500)	
R-square	0.275		0.323	
N	288		288	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.56: RQ2 third round of regressions for energy consumption per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	459720.600	*	623980.200	*
	(65377.050)		(96882.520)	

Table B.56: (continued)

Variables	OLS		Fixed Effects	
LRT Ridership	0.016	*	0.013	*
	(0.004)		(0.004)	
LRT DR Miles	-591.431		-401.034	
	(1541.341)		(1503.210)	
LRT Operating Expenses	-0.004	*	-0.003	
	(0.002)		(0.002)	
LRT Veh at Max Service	185.384		344.780	
	(1551.460)		(1505.682)	
LRT Pass Miles Traveled	-0.003	*	-0.003	*
	(0.001)		(0.001)	
LRT Energy Consumption	1.87E-06		1.34E-06	
	(1.00E-06)		(9.79E-07)	
Population Density	-56.172		-96.268	*
	(39.344)		(39.240)	
Housing Density	-183.161	*	-210.608	*
	(59.650)		(59.470)	
Employment Density	2437.503	*	3469.700	*
	(1105.229)		(1123.203)	
Ridership	-0.001	*	-0.001	*
	(2.28E-04)		(2.23E-04)	
Directional Route Miles	2.824		-6.026	
	(14.070)		(13.946)	
Operating Expenses	-8.57E-06		-9.80E-06	
	(1.01E-04)		(9.86E-05)	
Vehicles at Max Service	278.462	*	278.019	*
	(38.125)		(37.385)	
Years				
2001			-16179.020	
			(81688.510)	
2002			97009.270	
			(83281.490)	
2003			-135468.100	
			(83203.040)	
2004			-177492.000	*
			(81643.070)	
2005			-212422.200	*
			(82782.420)	
2006			-215326.200	*
			(83284.600)	
2007			-210274.700	*
			(84198.830)	

Table B.56: (continued)

Variables	OLS		Fixed Effects	
2008			-243777.800	*
			(84654.310)	
2009			-130465.600	
			(85810.810)	
2010			-154516.700	
			(88664.160)	
2011			-93639.440	
			(94994.910)	
R-square	0.611		0.655	
N	275		275	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>\|t\| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.57: RQ2 third round of regressions for CO2 intensity – basic model

Variables	OLS		Fixed Effects	
Constant	0.325	*	0.311	*
	(0.010)		(0.023)	
LRT Ridership	-1.94E-09		-1.67E-09	
	(1.36E-09)		(1.39E-09)	
LRT DR Miles	-0.002	*	-0.002	*
	-3.82E-04		(3.88E-04)	
LRT Operating Expenses	6.95E-11		-6.84E-11	
	(3.76E-10)		(4.03E-10)	
LRT Veh at Max Service	-4.50E-04		-4.86E-04	
	(0.001)		(0.001)	
LRT Pass Miles Traveled	2.94E-10		2.71E-10	
	(2.69E-10)		(2.73E-10)	
LRT Energy Consumption	2.09E-13		2.43E-13	
	(2.36E-13)		(2.41E-13)	
Years				
2001			-0.004	
			(0.030)	

Table B.57: (continued)

Variables	OLS	Fixed Effects
2002		0.023
		(0.030)
2003		0.001
		(0.029)
2004		0.031
		(0.029)
2005		0.018
		(0.029)
2006		0.011
		(0.029)
2007		0.017
		0.029
2008		-0.007
		(0.029)
2009		0.028
		(0.029)
2010		0.027
		(0.029)
2011		0.021
		(0.030)
R-square	0.415	0.426
N	288	288

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.58: RQ2 third round of regressions for CO2 intensity – expanded model

Variables	OLS		Fixed Effects	
Constant	0.384	*	0.428	*
	(0.022)		(0.034)	
LRT Ridership	-4.09E-09	*	-5.00E-09	*
	(1.45E-09)		(1.51E-09)	
LRT DR Miles	-0.002	*	-0.003	*
	(0.001)		(0.001)	

Table B.58: (continued)

Variables	OLS		Fixed Effects	
LRT Operating Expenses	1.01E-09		1.55E-09	*
	(6.03E-10)		(6.53E-10)	
LRT Veh at Max Service	-8.42E-05		-3.52E-05	
	(0.001)		(0.001)	
LRT Pass Miles Traveled	6.95E-10	*	8.22E-10	*
	(2.91E-10)		(2.96E-10)	
LRT Energy Consumption	-3.25E-14		-1.30E-13	
	(3.34E-13)		(3.39E-13)	
Population Density	-2.50E-06		-2.25E-06	
	(1.31E-05)		(1.36E-05)	
Housing Density	-2.80E-05		-4.04E-05	
	(1.99E-05)		(2.06E-05)	
Employment Density	-1.13E-04		-2.16E-04	
	(3.69E-04)		(3.89E-04)	
Ridership	-1.27E-11		-4.10E-11	
	(7.61E-11)		(7.74E-11)	
Directional Route Miles	-6.53E-06		-6.16E-06	
	(4.69E-06)		(4.83E-06)	
Operating Expenses	1.59E-11		2.91E-11	
	(3.37E-11)		(3.42E-11)	
Vehicles at Max Service	-4.51E-06		-6.64E-06	
	(1.27E-05)		(1.29E-05)	
Years				
2001			-0.009	
			(0.028)	
2002			0.013	
			(0.029)	
2003			-0.019	
			(0.029)	
2004			0.002	
			(0.028)	
2005			-0.018	
			(0.029)	
2006			-0.029	
			(0.029)	
2007			-0.028	
			(0.029)	
2008			-0.062	*
			(0.029)	
2009			-0.036	
			(0.030)	

Table B.58: (continued)

Variables	OLS		Fixed Effects	
2010			-0.045	
			(0.031)	
2011			-0.047	
R-square	0.454		0.477	
N	275		275	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05
Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.59: RQ2 third round of regressions for CO2 emissions per capita – basic model

Variables	OLS		Fixed Effects	
Constant	34.905	*	41.792	*
	(2.758)		(5.999)	
LRT Ridership	1.37E-07		5.49E-09	
	(3.68E-07)		(3.70E-07)	
LRT DR Miles	-0.111		-0.114	
	(0.103)		(0.103)	
LRT Operating Expenses	3.56E-07	*	4.43E-07	*
	-1.02E-07		(1.07E-07)	
LRT Veh at Max Service	0.087		0.095	
	(0.136)		(0.135)	
LRT Pass Miles Traveled	-4.20E-08		-2.65E-08	
	(7.29E-08)		(7.25E-08)	
LRT Energy Consumption	-1.38E-10	*	-1.68E-10	*
	(6.38E-11)		(6.39E-11)	
Years				
2001			-0.387	
			(7.873)	
2002			8.641	
			(7.890)	

Table B.59: (continued)

Variables	OLS		Fixed Effects	
2003			-6.488	
			(7.738)	
2004			-7.545	
			(7.610)	
2005			-10.836	
			(7.613)	
2006			-10.480	
			(7.620)	
2007			-12.490	
			(7.651)	
2008			-15.636	*
			(7.605)	
2009			-9.160	
			(7.595)	
2010			-11.262	
			(7.679)	
2011			-7.825	
			(8.052)	
R-square	0.119		0.168	
N	288		288	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.

Table B.60: RQ2 third round of regressions for CO2 emissions per capita – expanded model

Variables	OLS		Fixed Effects	
Constant	33.270	*	48.137	*
	(5.061)		(7.534)	
LRT Ridership	9.05E-07	*	6.37E-07	
	(3.36E-07)		(3.39E-07)	
LRT DR Miles	-0.112		-0.114	
	(0.119)		(0.117)	

Table B.60: (continued)

Variables	OLS		Fixed Effects	
LRT Operating Expenses	-3.40E-07	*	-1.70E-07	
	(1.40E-07)		(1.47E-07)	
LRT Veh at Max Service	-0.013		0.002	
	(0.120)		(0.117)	
LRT Pass Miles Traveled	-1.61E-07	*	-1.30E-07	
	(6.75E-08)		(6.64E-08)	
LRT Energy Consumption	1.32E-10		8.61E-11	
	(7.74E-11)		(7.62E-11)	
Population Density	-0.003		-0.005	
	(0.003)		(0.003)	
Housing Density	-0.013	*	-0.016	*
	(0.005)		(0.005)	
Employment Density	0.129		0.182	*
	(0.086)		(0.087)	
Ridership	-8.60E-08	*	-9.11E-08	*
	(1.77E-08)		(1.74E-08)	
Directional Route Miles	6.29E-04		8.35E-04	
	(0.001)		(0.001)	
Operating Expenses	3.08E-09		4.25E-09	
	(7.81E-09)		(7.67E-09)	
Vehicles at Max Service	0.018	*	1.77E-02	*
	(0.003)		(0.003)	
Years				
2001			-1.172	
			(6.353)	
2002			6.916	
			(6.477)	
2003			-9.547	
			(6.471)	
2004			-11.941	
			(6.349)	
2005			-15.970	*
			(6.438)	
2006			-16.253	*
			(6.477)	
2007			-16.225	*
			(6.548)	
2008			-19.695	*
			(6.583)	
2009			-13.194	*
			(6.673)	

Table B.60: (continued)

Variables	OLS	Fixed Effects	
2010		-14.116	*
		(6.895)	
2011		-11.442	
		(7.388)	
R-square	0.429	0.487	
N	275	275	

Source: Author's Calculations
Notes: Standard errors are in parenthesis. Significant variables are denoted by asterisks (*) with P>|t| = 0.05 Year 2000 is omitted, naturally coded. LRT emissions is omitted because of collinearity.