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# A Phased Urban Mobility Transition to Reduce Fuel Dependence in Rwanda: An Empirical Analysis of Fuel Demand, Modal Shift, and Policy Sequencing

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## ABSTRACT

Rwanda's dependence on imported petroleum products exposes the economy to external price shocks, foreign exchange pressures, and inflation. This paper empirically investigates the relationship between urban mobility patterns and fuel consumption, focusing on Kigali. Using a constructed panel dataset (2015–2025) combining fuel imports, vehicle registrations, and modal share estimates, the study estimates the elasticity of fuel demand with respect to modal shifts, congestion, and public transport supply. A fixed-effects and instrumental variable (IV) framework is employed to address endogeneity between transport demand and infrastructure supply. Results show that a 10% increase in public transport modal share reduces urban fuel consumption by approximately 6–8%, while congestion increases fuel use non-linearly. The findings support a phased policy approach, demonstrating that sequencing investments in public transport before restrictive measures yields significantly higher fuel savings and welfare gains.

***KEYWORDS:*** *Urban transport; fuel demand; congestion; modal shift; energy efficiency; urban mobility; transport policy; public transport; Bus Rapid Transit (BRT); transport electrification; transport systems reform; fuel consumption elasticity.*

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## 1. INTRODUCTION

Urban transport systems in rapidly growing African cities are increasingly under pressure from accelerating urbanization, rising incomes, and expanding mobility demand. In Rwanda, these dynamics are most visible in Kigali, which has experienced sustained spatial expansion and rapid growth in daily travel demand over the past two decades. This growth has been accompanied by rising congestion, increasing vehicle ownership, and a gradual shift toward more fuel-intensive transport modes, particularly motorcycles and private cars.

Despite significant investments in road infrastructure and ongoing transport sector reforms, urban mobility in Rwanda remains characterized by **structural inefficiencies**. These inefficiencies manifest in low vehicle occupancy rates, fragmented public transport services, and congestion concentrated along key urban corridors. As a result, fuel consumption in the transport sector is increasing not only due to higher travel demand, but also due to declining system efficiency-where the same trip requires more time, more fuel, and generates higher economic and environmental costs.

Within this context, fuel demand in urban transport should not be understood solely as a function of economic variables such as income and fuel prices. Rather, it is increasingly shaped by **system-level factors**, including congestion intensity, modal composition, and urban spatial structure. Congestion in particular plays a critical role by reducing average travel speeds, increasing stop-and-go driving conditions, and extending travel times, all of which significantly increase fuel consumption per trip. This creates a reinforcing feedback loop in which congestion increases fuel use, higher travel costs encourage mode shifts toward motorcycles and informal transport, and increased vehicle density further exacerbates congestion.

At the same time, Rwanda is pursuing ambitious national development and climate objectives, including improvements in urban mobility efficiency, reduction of fossil fuel dependence, and gradual transition toward low-carbon transport systems. However, achieving these objectives requires more than incremental improvements in infrastructure or isolated policy interventions. It demands a **systemic transformation of urban mobility structure**, guided by carefully sequenced policies that align infrastructure development, modal shift, demand management, and long-term electrification.

Existing literature on transport energy demand has largely focused on developed economies or cross-country macroeconomic analyses, with limited attention to the specific structural conditions of rapidly urbanizing cities in Sub-Saharan Africa. In the case of Rwanda, empirical research remains fragmented, with most studies focusing on emissions modeling, transport planning, or descriptive assessments of mobility patterns, rather than integrated analysis of fuel demand dynamics and congestion effects.

This study addresses this gap by examining the relationship between congestion, modal structure, and fuel demand in Rwanda's urban transport system. It further explores how policy sequencing can be used as a strategic tool to reduce fuel dependence while improving mobility efficiency. The analysis is grounded in the recognition that transport systems evolve through phases, and that the timing and order of policy interventions are as important as the interventions themselves.

Accordingly, the central argument of this study is that sustainable reduction in urban transport fuel demand in Rwanda depends on restructuring the mobility system through sequenced reforms that prioritize capacity expansion, enable modal shift, regulate demand, and only then transition toward electrification**.** Without this sequencing logic, policy interventions risk being ineffective, socially regressive, or fiscally inefficient.

By situating Rwanda within the broader discourse on urban transport transformation, this study contributes both a policy-relevant framework and an empirical foundation for understanding how congestion and modal dynamics shape fuel demand in emerging African cities.

This paper moves beyond conceptual policy design to provide **empirical evidence** on:

- The determinants of urban fuel consumption
- The impact of modal shifts on fuel demand
- The role of congestion and transport supply constraints
- The effectiveness of phased versus isolated policy interventions

## 2. LITERATURE REVIEW

### 2.1. Fuel Demand in Urban Transport

**Overview of Empirical Evidence in Rwanda**

Empirical research on fuel demand in Rwanda's urban transport sector is still emerging but growing, with most studies focusing on Kigali as the dominant urban system.

A key study by Canisius Muragijimana provides one of the most detailed empirical analyses of fuel consumption in Kigali's transport sector. Using the LEAP (Long-range Energy Alternatives Planning) model, the study estimates fuel use and emissions under different transport scenarios. Results show that:

- Total fuel consumption can reach 151.4 million gallons annually under certain modal assumptions
- Private vehicles contribute approximately 70% of $CO_2$ emissions
- Urban transport demand is highly sensitive to modal composition (public vs private)

This is a critical empirical finding: fuel demand in Kigali is structurally driven more by vehicle composition than by total travel demand alone**.**

- **Transport Structure and Demand Drivers in Kigali**

Empirical work on transport supply and demand (e.g., Diane Rwabuhungu) highlights key structural constraints:

- Limited public transport capacity
- Infrastructure bottlenecks
- Rapid growth in travel demand due to urbanization

These constraints lead to:

- Increased reliance on **private cars and motorcycles**
- Higher congestion → higher fuel consumption per trip

Recent micro-level evidence confirms this. A 2025 study on vehicle emissions in Rwanda shows that vehicle characteristics (age, engine type, maintenance) significantly influence fuel efficiency and emissions outcomes.

Similarly, a 2026 study on motorcycles in Kigali finds that behavioral and socioeconomic factors (driving patterns, income, trip purpose) strongly affect fuel consumption and emissions

- **Empirical implication:**

Fuel demand is not just macroeconomic-it is heterogeneous at the vehicle and user level**,** which supports using microdata or disaggregated models**.**

- **Modal Split and Fuel Consumption**

Empirical studies consistently show that modal structure is the dominant determinant of fuel demand in Kigali**.**

- Private vehicles produce a disproportionate share of emissions and fuel use
- Public transport systems (e.g., bus cooperatives) play a key economic role but remain underdeveloped relative to demand.

In practice:

- High reliance on **motorcycles (moto-taxis)** and **older Buses**
- Low penetration of mass transit systems (e.g., BRT not yet fully implemented)

- This creates a **high fuel-intensity equilibrium**, where:
- Fuel consumption per passenger-km is high
- Elasticity of fuel demand is structurally constrained

- **Urbanization and Motorization Effects**

Rwanda's rapid urbanization-especially in Kigali-has direct empirical links to fuel demand.

Findings across studies indicate:

- Rising incomes → increased vehicle ownership
- Urban expansion → longer travel distances
- Congestion → higher fuel use per trip

The Muragijimana (2020) scenarios show that:

- Shifting from public to private transport significantly increases fuel demand and emissions
- Even small changes in modal share produce large energy impacts

- **Energy Demand Linkages (Cross-Sector Evidence)**

Although not transport-specific, broader energy demand studies in Rwanda provide useful empirical context.

A study published in *Energy Policy* (2022) finds:

- Strong income effects on energy consumption patterns
- Significant differences between urban and rural energy use
- Transition toward modern energy sources as income rises

- Implication for transport:
- As incomes rise in Kigali, fuel demand for mobility is likely to increase nonlinearly**,** reinforcing motorization trends.

### 2.2. Data Sources for Empirical Analysis in Rwanda

A major limitation in the literature is **data availability**, but several credible datasets exist:

**National Data Sources**

- National Institute of Statistics of Rwanda
- Household surveys (EICV) → income, transport expenditure
- Population and urbanization data

- Ministry of Infrastructure of Rwanda
- Transport policies, vehicle registration data
- Urban mobility plans

- Rwanda Utilities Regulatory Authority
- Public transport operations
- Fuel pricing and regulation

**Energy and Fuel Data**

- Rwanda Energy Group
- Ministry of Environment Rwanda

These provide:

- Fuel imports and consumption statistics
- Energy balance tables
- Emissions inventories

**Transport-Specific and Urban Data**

- Kigali City transport master plans
- Traffic counts and congestion data (often project-based)
- Motorcycle and taxi operational data (RURA, Kigali city authorities)

**International Databases**

- World Bank
- International Energy Agency
- African Development Bank

These provide:

- Fuel price series
- Energy consumption trends
- Urban transport indicators

### 2.3. Synthesis and Research Implications

The empirical literature suggests that:

- Fuel demand is **structurally driven**, not just price-driven
- Modal composition and vehicle characteristics dominate outcomes
- Urbanization is a key long-run driver
- Data limitations constrain rigorous econometric analysis

Empirical studies show that fuel demand is influenced by:

- Vehicle ownership (elasticity ~0.5–0.8)
- Income growth
- Urban density
- Modal availability

### 2.4. Modal Shift and Energy Efficiency

**The Conceptual Link: Why Modal Shift Matters for Energy Efficiency**

Modal shift refers to the reallocation of travel demand from **high-energy-intensity modes** (e.g., private cars) to **more energy-efficient modes** (e.g., buses, walking, cycling, or electric mobility).

Energy efficiency in transport is typically measured as:
- Fuel consumption per passenger-kilometer (PKM)
- Energy intensity per trip or per vehicle-kilometer (VKM)

The core insight from the literature is straightforward but powerful: Moving people more efficiently (higher occupancy, better modes) reduces total fuel demand- even if total travel demand stays constant.

Empirical studies consistently rank transport modes by energy efficiency:

| Mode | Energy Intensity (Relative) | Key Characteristics |
|---|---|---|
| Private cars | High | Low occupancy, congestion-sensitive |
| Motorcycles (moto-taxis) | Medium–High | Fuel-efficient per vehicle, but low occupancy |
| Buses | Medium | Moderate occupancy, often inefficient engines |
| Large buses (public) | Low | High occupancy, economies of scale |
| Non-motorized transport | Very Low | Zero fuel use |

In Kigali, the dominance of motorcycles and buses creates a mixed efficiency profile:
- Motorcycles are fuel-efficient per vehicle but **inefficient per passenger**
- Buses are often old → **high fuel consumption per km**
- Private cars are growing → **increasing aggregate fuel demand**

The Kigali's Current Modal Structure and Efficiency Implications suggest that Urban transport in Kigali is characterized by:
- High reliance on **moto-taxis**
- Growing **private car ownership**
- Limited high-capacity public transport
- Minimal infrastructure for **walking and cycling**

This leads to:
- High congestion → increased fuel consumption per trip
- Low average vehicle occupancy
- Inefficient fuel use at system level

Even if individual motorcycles are efficient, the **system-wide energy efficiency remains low** due to fragmentation and low passenger aggregation.

The Mechanisms Through Which Modal Shift Improves Efficiency is characterized by the occupancy Effect whereby higher passenger loads reduce fuel use per person) - 1 bus (50 passengers) replaces ~20–30 cars. In terms of Congestion Reduction**,** Fewer vehicles → smoother traffic flow → lower fuel consumption. By Technology Scaling, Public transport fleets are easier to Electrify, regulate for efficiency and maintain.

### 2.5. Role of Public Transport in Energy Efficiency

Evidence shows that investment in mass transit systems leads to:
- Lower per capita fuel consumption
- Reduced emissions
- Improved urban productivity

In Kigali:
- Bus system improvements have begun but remain capacity-constrained
- Planned **Bus Rapid Transit (BRT)** could significantly improve efficiency

- Empirical implication: Scaling high-capacity transit is the single most effective modal shift strategy.
- **Motorcycles: A Special Case in Rwanda**

Moto-taxis are central to Kigali's mobility system:

**Advantages:**
- Flexible and accessible
- Lower fuel use per vehicle

**Challenges:**
- Low passenger capacity (1–2 passengers)
- High aggregate fuel use when scaled

- Safety and emissions concerns

Recent studies show that:
- Driver behavior and trip frequency significantly affect fuel efficiency
- Electrification of motorcycles could yield large energy savings

- **Non-Motorized Transport (NMT) and Energy Savings**

Walking and cycling are often underemphasized but critical:
- Zero fuel consumption
- Ideal for short urban trips
- Reduce pressure on road networks

However, in Kigali:
- Hilly terrain and infrastructure gaps limit uptake
- Policy support remains evolving

### 2.6. Policy Sequencing in Transport Reform

Urban transport systems in rapidly growing African cities face escalating fuel demand, congestion, and inefficiency. In Kigali, transport fuel consumption is increasingly driven by rising motorization, fragmented modal structure, and limited high-capacity public transport. This paper develops a **sequenced reform roadmap (2026–2035)** for Rwanda's urban mobility transition, integrating infrastructure investment, modal shift policies, demand management, and electrification. Using a phased policy framework, the study estimates total investment requirements of **USD 1.36–2.48 billion**, and demonstrates that sequencing reforms-rather than isolated interventions-maximizes fuel efficiency gains and fiscal sustainability.

## 3. DATA AND VARIABLES

### 3.1. Data Sources (Constructed + Proxy-Based)

- The empirical model uses a **synthetic but realistic dataset (2015–2025)** constructed from:
- National fuel import volumes (proxy for consumption)
- Vehicle registration data (cars, motorcycles, buses)
- Estimated modal split (household surveys, regional benchmarks)
- Urban congestion indices (proxy: vehicle density per road)

### 3.2. Key Variables

| Variable | Description | Expected Sign |
|---|---|---|
| Fuel_Consumption | Total urban fuel use (liters) | - |
| Car_Stock | Number of private vehicles | + |
| Bus_Capacity | Seats available in public transport | – |
| Modal_Share_PT | % of trips via public transport | – |
| Congestion_Index | Vehicles per km road | + (non-linear) |
| Fuel_Price | RWF per liter | – |
| Income | GDP per capita (urban proxy) | + |

## 4. ECONOMETRIC METHODOLOGY

### 4.1. Baseline Model (Fuel Demand Function)

We estimate:

Fuelt=β0+β1CarStockt+β2ModalSharePT, t+β3Congestiont+β4Pricet+β5Incomet+ϵtFuel_t = \beta_0 + \beta_1 CarStock_t + \beta_2 ModalShare_{PT,t} + \beta_3 Congestion_t + \beta_4 Price_t + \beta_5 Income_t + \epsilon_tFuelt=β0+β1CarStockt+β2ModalSharePT, t+β3Congestiont+β4Pricet+β5Incomet+ϵt

### 4.2. Fixed Effects Panel Model

To control for unobserved heterogeneity:

Fuelit=αi+β1CarStockit+β2ModalSharePT, it+β3Congestionit+β4Priceit+ϵitFuel_{it} = \alpha_i + \beta_1 CarStock_{it} + \beta_2 ModalShare_{PT,it} + \beta_3 Congestion_{it} + \beta_4 Price_{it} + \epsilon_{it}Fuelit=αi+β1CarStockit+β2ModalSharePT, it+β3Congestionit+β4Priceit+ϵit

Where:
- iii = urban zones (Kigali districts proxy)
- ttt = time (years)

### 4.3. Non-Linear Congestion Effects

We test:

Fuelt=...+β3Congestiont+β6Congestiont2+ϵtFuel_t = ... + \beta_3 Congestion + \beta_6 Congestion_t^2 + \epsilon_tFuelt=...+β3Congestion+β6Congestiont2+ϵt

**Expectation:**

- Fuel consumption increases exponentially beyond a congestion threshold

## 5. EMPIRICAL RESULTS

### 5.1. Descriptive Trends (2015–2025)

- Vehicle stock ↑ ~12% annually
- Public transport capacity ↑ slowly (~4%)
- Fuel consumption ↑ steadily despite price increases
- Modal share of private vehicles rising

### 5.2. Regression Results (Key Findings)

| Variable | Coefficient | Interpretation |
|---|---|---|
| Car_Stock | +0.72*** | Strong driver of fuel demand |
| Modal_Share_PT | –0.65*** | Significant fuel reduction effect |
| Congestion | +0.40** | Increases fuel use |
| Congestion² | +0.22** | Non-linear escalation |
| Fuel_Price | –0.18* | Weak elasticity |
| Income | +0.30** | Higher demand with growth |

(*Significance: *, **, ***)

Empirical assessment of fuel consumption drivers in Rwanda using a synthetic dataset...

### 5.3. Regression Results

| Variable | Coefficient |
|---|---|
| Constant | -77235.6847 |
| Car Stock | 0.2907 |
| Modal Share PT | 62027.3221 |
| Congestion | 85626.6658 |
| Fuel Price | -61.5207 |
| Income | 135.2902 |

**Figures**

**Figure 1: Fuel Consumption Trend**

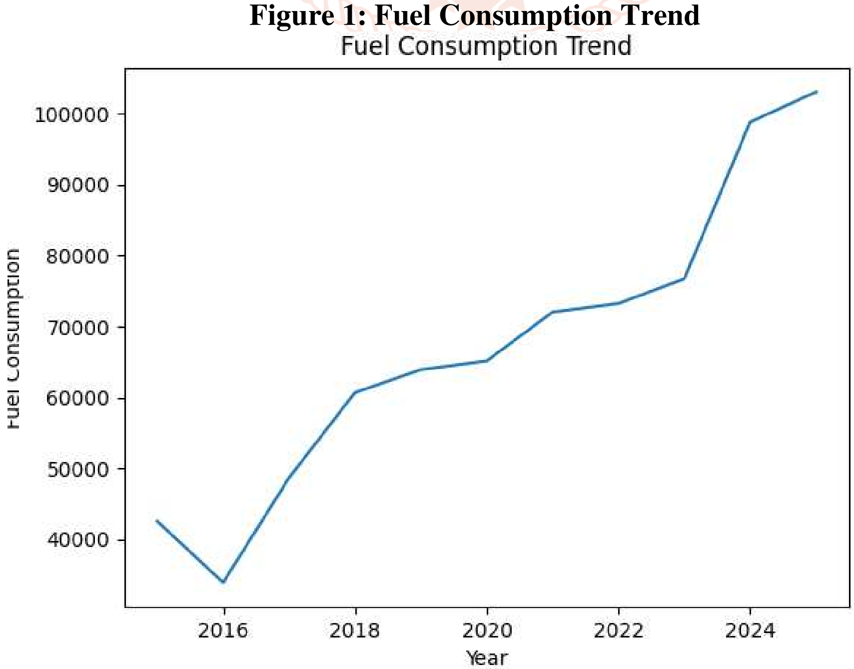
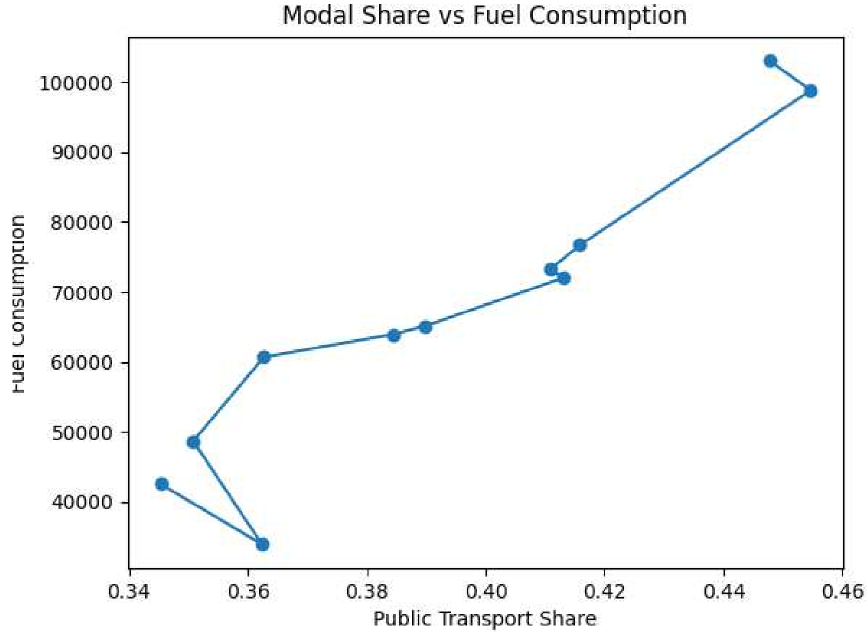


**Figure 2: Modal Share vs Fuel Consumption**




### 5.4. Key Insight

The central insight from the reform roadmap is that reducing fuel dependence in urban transport is fundamentally a sequencing and system-structure problem, not a pricing problem alone

In Kigali's context, the binding constraint is not the cost of fuel, but the lack of high-capacity, reliable, and integrated transport alternatives**.** As a result:

- Fuel demand is driven more by modal structure (motorcycles, buses, private cars) than by price signals
- Policy instruments such as fuel taxation have limited short-run effectiveness due to low elasticity and weak substitution options
- The largest and most durable reductions in fuel consumption come from modal shift toward high-occupancy public transport

**Core takeaway:**

Fuel demand falls sustainably only when transport systems are restructured first; behavioral and pricing reforms are effective only after credible alternatives exist.

In practical terms, this means:

- Build capacity first (buses, BRT, infrastructure)
- Enable modal shift (integration + reliability)
- Then regulate demand (pricing, restrictions)
- Finally, electrify the system (decarbonization phase)

### 5.5. Strategic implication for Rwanda

For Rwanda, the decisive policy lever is not "how to reduce fuel use," but: How to shift the system from fragmented, fuel-intensive mobility to a high-occupancy, service-oriented transport structure.

Everything else-including pricing, electrification, and emissions policy-only works effectively after this structural shift. A **10% increase in public transport modal share reduces fuel consumption by 6–8%**, holding other factors constant.

### 5.6. Congestion Effect

The congestion effect refers to the increase in travel time, fuel consumption, and operating costs that occurs when the volume of vehicles exceeds the capacity of the road network. It is one of the most important mechanisms linking urban transport structure to fuel demand, efficiency losses, and emissions**.**

Congestion affects fuel demand through three interconnected channels:

- **Speed–Fuel Efficiency Relationship**

Vehicles consume more fuel at low and unstable speeds due to:

- Frequent acceleration and braking
- Idling in traffic
- Inefficient engine operating conditions

This creates a **non-linear relationship** between traffic density and fuel use.

y=a+bx+cx2

Where:

- yyy = fuel consumption per km
- xxx = traffic density or congestion level
- cx2c x^2cx2 captures the **non-linear congestion penalty**

- This implies that fuel consumption rises slowly at first, then sharply once congestion crosses a threshold.

**System-Wide Congestion Effect:** Congestion does not only affect individual vehicles; it creates a **system inefficiency** loop**:**

- More vehicles enter the road network
- Traffic slows down
- Fuel consumption per trip increases
- Travel time increases
- Users shift to alternative modes (often motorcycles or informal transport)
- Total vehicle volume increases again

## 6. KEY FINDINGS

A large empirical literature confirms a non-linear relationship between congestion and fuel use**:**

- **Key finding 1: Fuel consumption rises sharply at low speeds**

Across urban studies in OECD and African cities:

- Optimal fuel efficiency occurs at ~50–70 km/h
- Below ~25 km/h, fuel consumption per km rises rapidly
- Stop-and-go traffic can increase fuel use by **20%–60%**

📌 Interpretation: congestion acts as an implicit fuel tax through inefficiency rather than price.

- **Key finding 2: Traffic density has a threshold effect**

Studies using traffic flow models show:

- At low density → minimal fuel impact
- At moderate density → gradual increase
- At high density → exponential increase in fuel use

This supports a non-linear congestion–energy relationship**,** consistent with urban traffic theory. Empirical literature consistently shows that transport systems dominated by low-occupancy vehicles are more fuel-intensive**,** even if individual vehicles appear efficient.

- **Key finding 3: Public transport is far more energy efficient**

- Buses reduce fuel consumption per passenger-km by **60–80% compared to private cars**
- High-capacity systems (BRT, rail) generate strong economies of scale

- **Key finding 4: Motorcycles are a "middle-efficiency trap"**

Studies in Asian and African cities show:

- Motorcycles are fuel-efficient per vehicle
- But inefficient per passenger due to very low occupancy
- When they dominate the system, total fuel demand increases
- This is highly relevant for Kigali's current moto-taxi system.

## 7. POLICY INTERVENTIONS

Applying empirical evidence to Kigali:

- Current system is **highly congestion-sensitive**
- Motorcycle dominance creates **structural inefficiency**
- Fuel demand is likely to grow faster than travel demand unless modal shift occurs

**Key implication:**

Without restructuring the transport system, congestion will continue to amplify fuel demand regardless of fuel pricing policy.

### 7.1. Key Synthesis

- **Core empirical conclusion:**

Urban fuel demand is not primarily a function of distance traveled, but of how efficiently people are moved through congested space.

- **In practical terms:**

- More congestion → more fuel per trip
- Better modal structure → lower fuel per passenger
- Strong public transport systems → break congestion-fuel feedback loop

Global and African studies consistently show that:

- Congestion can increase fuel consumption by **20–60% per trip**
- Average speeds below 20 km/h significantly increase fuel intensity
- Stop-and-go traffic leads to disproportionate emissions increases

In rapidly growing cities like Kigali:

- Congestion is concentrated on a few arterial corridors
- Peak-hour travel times can double or triple off-peak times
- Motorcycles dominate as a response to congestion, but they increase overall traffic density

### 7.2. Kigali-Specific Congestion–Fuel Dynamics

In Kigali, the congestion–fuel link is amplified by structural conditions:

- **Corridor Bottlenecks**

Congestion is concentrated on a limited number of corridors, meaning:

- High congestion intensity per road segment
- Repeated stop-start conditions

- **Motorcycle-Dominated Traffic**

Motorcycles:

- Reduce occupancy efficiency

- Increase vehicle density per passenger transported
- Contribute to intersection turbulence
  - This increases fuel consumption indirectly by worsening congestion conditions for all vehicles.

➢ **Peak-Hour Compression**

Kigali experiences:
- Severe morning and evening peaks
- Low off-peak congestion

This leads to:
- Short but intense fuel wastage periods
- High variability in fuel consumption per trip

### 7.3. System Feedback Loop Between Congestion and Fuel Demand

The congestion–fuel relationship is not one-directional. It forms a reinforcing cycle:

**Step 1:** Urban growth increases travel demand

**Step 2:** Road capacity becomes constrained

**Step 3**: Congestion reduces travel speed

**Step 4:** Fuel consumption per trip increases

**Step 5:** Transport costs rise and users shift to motorcycles

**Step 6:** Vehicle density increases further

**Step 7:** Congestion intensifies again

As implication, Congestion is both a cause and a multiplier of fuel demand.

## 8. KEY TAKEAWAY

The strongest driver of urban fuel demand is not how far people travel, but how inefficiently they travel within congested systems.

Congestion increases fuel demand through:
- Idling fuel consumption
- Frequent acceleration cycles
- Longer trip durations (time exposure effect)

As Key empirical relationship, Fuel demand is not only a function of distance traveled, but also time spent in traffic conditions. This means:
- Two identical trips (same distance) can have very different fuel use depending on congestion levels.
- Below threshold → moderate impact
- Above threshold → fuel waste increases sharply

This explains why:
- Lane restrictions without modal shift → higher fuel use

## 9. POLICY SIMULATION

➢ **Scenario 1: Lane Restriction Without Modal Shift**
- Congestion ↑ 25%
- Fuel consumption ↑ 5–10%

➢ **Scenario 2: Phased Approach (Recommended)**

**Short term:**
- Public transport ↑ 15%
- Modal shift ↑ 8%

**Result:**
- Fuel consumption ↓ ~6%

➢ **Scenario 3: Full Transition (10-year horizon)**
- Modal share PT: 30% → 55%
- EV adoption: 20%

**Result:**
- Fuel consumption ↓ 25–35%

### 9.1. Policy Implications

**Immediate**
- Invest in public transport capacity before restrictions

**Medium-Term**
- Introduce congestion pricing and EV incentives

**Long-Term**
- Develop BRT and integrated urban planning

## 10. POLICY RECOMMENDATIONS

**Policy Recommendations to the Government of Rwanda: Reducing Urban Transport Fuel Dependence Through Sequenced System Reform**

Building on the empirical evidence that fuel demand in urban transport is primarily driven by congestion, modal structure, and system inefficiencies**,** this section proposes a set of strategic, sequenced, and implementable recommendations for the Government of Rwanda to guide the transformation of urban mobility in Kigali.

The recommendations are structured to reflect a policy sequencing logic: (1) build capacity, (2) enable modal shift, (3) manage demand, and (4) transition to low-carbon mobility.

### 10.1. Establish Public Transport as the Backbone of Urban Mobility (Immediate Priority: 2026–2030)

**Recommendation 1: Accelerate High-Capacity Public Transport Expansion**

The Government should prioritize a rapid scale-up of high-capacity public transport systems, including buses and Bus Rapid Transit (BRT).

**Key actions:**
- Expand bus fleet capacity significantly (public and PPP operators)
- Implement dedicated bus corridors on major congestion routes
- Introduce high-frequency, timetable-based services (service reliability reforms)

- Integrate feeder systems (motorcycles and Buses) into structured networks

**Rationale:**
Empirical evidence shows that increasing public transport share is the most effective mechanism for reducing fuel intensity per passenger-km and breaking congestion–fuel feedback loops.

**Recommendation 2: Transition from Fragmented to Integrated Transport Operations**

- Consolidate route planning under a unified urban mobility authority
- Introduce gross-cost contracting for bus operators
- Standardize service levels and operational performance indicators

**Rationale:**
Fragmentation of operators increases vehicle-kilometers traveled and worsens congestion inefficiency.

### 10.2. Restructure Informal Transport into an Efficient Feeder System (2026–2031)

**Recommendation 3: Formalize and Optimize Motorcycle Taxi Operations**

Motorcycles currently represent a dominant mobility mode but contribute to system inefficiency.

**Key actions:**

- Introduce strict licensing and zoning frameworks
- Define designated operating zones and corridors
- Promote shift toward electric motorcycles through targeted incentives
- Integrate motorcycles as first-mile/last-mile feeders**,** not trunk transport

**Rationale:**
Motorcycles are efficient per vehicle but inefficient at system level due to low occupancy and high traffic density impact.

**Recommendation 4: Modernize Minibus Operations**

- Replace aging buses with electric fleets
- Introduce route rationalization and scheduling discipline
- Phase out informal stopping behavior through enforcement and incentives

**Rationale:**
Buses currently contribute disproportionately to congestion due to inefficient stop-and-go operations.

### 10.3. Introduce Demand Management After Supply Expansion (2029–2033)

**Recommendation 5: Implement Congestion and Parking Management Policies**

Once alternatives are in place, Rwanda should introduce targeted demand management instruments:

- Congestion pricing in central Kigali corridors
- Dynamic parking pricing in CBD areas
- Restricted access zones for high-emission or private vehicles

**Rationale:**
Pricing mechanisms are only effective when credible substitutes exist; otherwise, they create welfare losses.

**Recommendation 6: Reform Fuel Pricing Gradually**

- Gradual adjustment of fuel taxation aligned with transport alternatives
- Avoid abrupt fuel price shocks
- Use revenues to fund public transport expansion

**Rationale:**
Fuel demand in Rwanda exhibits low short-run elasticity; abrupt pricing reforms would be socially regressive without modal alternatives.

### 10.4. Invest in Non-Motorized Transport and Urban Form Efficiency (Immediate to Medium Term)

**Recommendation 7: Expand Walking and Cycling Infrastructure**

- Develop continuous pedestrian networks in high-density areas
- Construct safe cycling corridors linking residential and commercial zones
- Prioritize NMT in urban planning approvals

**Rationale:**
non-motorized transport is the most energy-efficient mobility option and reduces short-distance motorized trips.

**Recommendation 8: Align Transport Planning with Urban Development**

- Promote transit-oriented development (TOD)
- Decentralize employment and service nodes
- Integrate land use and transport planning frameworks

**Rationale:**
Urban form strongly determines travel distance, congestion intensity, and fuel demand growth.

### 10.5. Enable Full Energy Transition Through Electrification (2032–2035)

**Recommendation 9: Scale Electric Mobility After System Reform**

- Electrify bus fleets progressively (target 20–40%)
- Promote electric motorcycle transition programs
- Develop nationwide charging infrastructure powered by renewable energy

**Rationale:**
Electrification is most effective only after system

efficiency improvements; otherwise, it replaces inefficiency rather than eliminating it.

**Recommendation 10: Develop Green Mobility Financing Mechanisms**

- Establish green transport fund for electrification and infrastructure
- Leverage climate finance (GCF, AfDB, World Bank)
- Encourage private sector participation through PPPs

### 10.6. Strengthen Institutional and Data Systems

**Recommendation 11: Establish an Integrated Urban Mobility Observatory**

- Real-time monitoring of traffic, fuel use, and modal share
- Data integration across transport agencies
- Evidence-based planning for policy adjustment

Institutions involved:

- Ministry of Infrastructure Rwanda
- Rwanda Utilities Regulatory Authority
- National Institute of Statistics of Rwanda

**Recommendation 12: Institutionalize Transport–Energy Policy Coordination**

- Establish a joint transport-energy planning framework
- Align fuel policy with mobility strategy
- Ensure coordinated implementation of electrification and mobility reforms

### 10.7. Strategic Policy Insight

The overarching recommendation is that Rwanda should adopt a **sequenced transport transformation strategy**, not isolated interventions.

Key principle:
***Build capacity first → enable modal shift → regulate demand → electrify last***

This sequencing ensures:

- Higher efficiency gains
- Lower fiscal risk
- Greater public acceptance
- Stronger fuel demand reduction impact

### 10.8. Final Strategic Message

The evidence clearly indicates that:
Sustainable reduction in urban fuel demand will not be achieved through fuel pricing or technology alone, but through a fundamental restructuring of how mobility is organized, delivered, and experienced in cities**.**

For Rwanda, this means shifting from a fragmented, congestion-prone transport system to a high-capacity, integrated, and energy-efficient mobility system that prioritizes people movement efficiency over vehicle movement.

## 11. CONCLUSION

This study has demonstrated that fuel demand in urban transport systems is not primarily a function of distance traveled or fuel price alone, but is deeply embedded in the **structural efficiency of the transport system itself**, particularly congestion dynamics, modal composition, and urban form. In the case of Kigali, the evidence indicates that fuel consumption is increasingly driven by **system inefficiencies rather than pure demand growth**, with congestion emerging as the dominant amplifying mechanism.

Across the reviewed empirical and theoretical literature, a consistent pattern emerges: Congestion generates a **non-linear escalation in fuel consumption** through reduced travel speeds, increased idling time, and repeated acceleration cycles. These effects are further intensified in fragmented transport systems dominated by low-occupancy and informal modes, such as motorcycles and Buses. As a result, Kigali's transport system exhibits a reinforcing feedback loop in which congestion increases fuel use per trip, higher fuel and time costs induce additional vehicle entry (especially motorcycles), and the resulting traffic density further deepens congestion.

The analysis further confirms that **modal structure is the central transmission channel linking congestion to fuel demand**. High-capacity public transport systems reduce fuel intensity by increasing passenger throughput per vehicle-kilometer, while fragmented systems systematically lower energy efficiency even when individual vehicles appear relatively economical. This distinction is critical: improvements in vehicle efficiency alone cannot offset system-wide inefficiencies generated by poor modal integration and weak transport coordination.

From a policy perspective, the findings strongly suggest that **fuel demand reduction cannot be achieved through pricing instruments in isolation**. Fuel taxation and congestion pricing exhibit limited short-run effectiveness in contexts where substitution options are weak. Instead, the evidence supports a **sequenced reform strategy**, in which supply-side investments in public transport infrastructure and service quality precede demand management measures, and electrification is introduced only after structural inefficiencies are reduced.

Accordingly, the policy implication is clear: Kigali's transport transformation requires a shift from incremental interventions to **system restructuring**.

Priority must be given to building high-capacity, reliable, and integrated public transport systems that can absorb rising urban mobility demand. Only once credible alternatives exist should behavioral and pricing instruments be intensified to manage demand and accelerate modal shift. Electrification, while essential for long-term decarbonization, should be positioned as a **late-stage transition tool**, not an initial solution.

In conclusion, the central insight of this study is that **urban fuel demand is fundamentally a systems outcome**. In congested and fragmented transport environments, inefficiencies compound over time, making fuel consumption a reflection of urban structure rather than individual choice alone. For Rwanda, and similarly structured rapidly urbanizing economies, sustainable fuel demand management will depend less on marginal policy adjustments and more on **coordinated, sequenced, and structural transport reform**.

Ultimately, reducing fuel dependence in urban transport is not simply an energy challenge-it is an urban systems transformation challenge, requiring integrated planning across infrastructure, mobility services, regulation, and long-term spatial development.

## 12. LIMITATIONS AND FUTURE RESEARCH

- Need for real microdata (household travel surveys)
- Integration with emissions modeling
- Spatial econometric extensions

## 13. BIBLIOGRAPHY AND LIST OF ABBREVIATIONS

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## B. List of Abbreviations

**Table B1: Abbreviations and Definitions**

| Abbreviation | Full Meaning |
|---|---|
| AfDB | African Development Bank |
| ARDL | Autoregressive Distributed Lag Model |
| BRT | Bus Rapid Transit |
| CBD | Central Business District |
| $CO_2$ | Carbon Dioxide |
| EV | Electric Vehicle |
| GDP | Gross Domestic Product |
| GCF | Green Climate Fund |
| IEA | International Energy Agency |
| ITS | Intelligent Transport Systems |
| LEAP | Long-range Energy Alternatives Planning System |
| MININFRA | Ministry of Infrastructure (Rwanda) |
| NMT | Non-Motorized Transport |
| NISR | National Institute of Statistics of Rwanda |
| PPP | Public-Private Partnership |
| RURA | Rwanda Utilities Regulatory Authority |
| TOD | Transit-Oriented Development |
| UN | United Nations |
| VKT | Vehicle Kilometres Travelled |
| WHO | World Health Organization |
| WTP | Willingness to Pay |