

Trip Generation and Emission Estimation for a Toll Access-Integrated Economic Area: A Peri-Urban Corridor Case Study

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Received : July 14, 2026

Revised : July 17, 2026

Accepted : July 21, 2026

Online : October 7, 2026

Abstract

This study examines the traffic and environmental impacts of integrating a toll access node with an Integrated Economic Area (IEA) in a peri-urban corridor along the Yogyakarta–Bawen Toll Road. A quantitative framework decomposes traffic demand into existing, toll-induced, and IEA-generated trips, projects each over 40 years, and estimates VKT-based emissions. Results show strong demand amplification, especially early in operation, as combined trip generation accelerates growth beyond conventional projections. While the Banyurejo T-intersection performs acceptably under planned upgrades, environmental impact is significant: annual VKT rises more than fourteen-fold, with CO₂ emissions climbing from about 4,700 to over 67,000 tonnes/year by 2070. These findings expose the limits of conventional impact assessments focused on traffic alone and highlight the need for integrated frameworks that combine mobility and emissions dimensions. The novelty of this study lies in its integrated decomposition framework, which jointly quantifies existing, toll-induced, and land-use-generated traffic components and links their long-term projections directly to vehicle-kilometers-traveled-based emission estimation, an integration rarely addressed in conventional transportation impact assessments.

Keywords *Peri-Urban Corridor, Integrated Economic Area (IEA), Traffic Demand Projection, Vehicle Kilometers Traveled (VKT), Carbon Emissions, Toll-Induced Traffic, Trip Generation Modeling*

INTRODUCTION

The expansion of toll road infrastructure in developing countries is a major driver of spatial transformation in peri-urban and rural corridors, improving regional accessibility (Rajendran et al., 2024). In Indonesia, the Trans-Java toll network has accelerated land-use change, creating new economic clusters around toll access points (Aditya & Husna, 2022; Shofy & Wibowo, 2023). However, without proactive planning, this often results in uncontrolled urban sprawl, inefficient mobility, and rising environmental externalities (Brueckner, 2001; Kasraian et al., 2016; Pojani & Stead, 2015; Xiao et al., 2025).

The Yogyakarta–Bawen Toll Road Section 1, in a predominantly rural corridor, exemplifies infrastructure-induced spatial transition. To address the risks of unregulated peri-urban expansion, the Governor of DIY has initiated a community-based IEA near the toll access (Governor of the Special Region of Yogyakarta, 2026), regulating growth, ensuring local communities benefit, and serving as an intermediate mobility node that redistributes traffic away from urban core exits.

Despite its importance, evaluating such developments remains limited within conventional

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transportation frameworks ([Lopane et al., 2023](#); [Mukherjee & Kadali, 2022](#); [Yadav & Ghodmare, 2021](#)), which rely on the four-step model, emphasizing traffic performance while overlooking emissions ([Guo et al., 2020](#); [Mladenovic & Trifunovic, 2014](#); [Mulya et al., 2024](#))—significant in rural areas where new demand alters baseline conditions.

Trip generation, the first stage of demand modeling, determines travel demand and influences distribution, modal split, and assignment ([McNally, 2007](#)). Conventional models, however, inadequately represent hybrid developments such as IEAs adjacent to toll access, which generate complex travel behavior ([Chen et al., 2021](#); [Goh et al., 2023](#); [Liu et al., 2015](#); [Perdana et al., 2024](#)).

Accordingly, this study seeks to answer two research questions: (1) how do toll-induced traffic, IEA-generated trips, and existing background traffic jointly shape long-term travel demand at a peri-urban toll access node, and (2) to what extent does this combined demand translate into vehicular emissions over a multi-decade horizon. To address these questions, this study develops a 40-year trip generation model for a toll access-IEA corridor and estimates resulting emissions, integrating demand analysis with environmental assessment to provide a holistic framework for evaluating infrastructure-induced development in the Global South.

LITERATURE REVIEW

A considerable body of research has developed trip generation models as a core component of transportation planning. Early approaches relied on regression and cross-classification methods that link trip-making to socioeconomic and land-use variables such as income and vehicle ownership ([Institute of Transportation Engineers, 2017](#); [Ortúzar & Willumsen, 2011](#)). More recent studies incorporate advanced techniques, including artificial neural networks and adaptive models, to improve prediction accuracy in complex urban environments ([Abu-Eisheh et al., 2024](#)).

Trip generation estimation largely relies on standardized databases, notably the ITE Trip Generation Manual. However, several studies highlight limitations of applying ITE-based models directly in developing countries. [Mukherjee and Kadali \(2022\)](#) found that differences in socioeconomic characteristics and modal composition significantly affect trip-making behavior, while [Abu-Eisheh et al. \(2024\)](#) emphasized the need for locally calibrated models in emerging regions.

Recent research has also examined simplified trip generation models using physical indicators such as Gross Floor Area (GFA). [Breški et al. \(2025\)](#) showed that GFA-based regression models achieve high explanatory power in commercial developments, though these studies generally focus on single-function land uses such as shopping centers or residential areas.

Mixed-use developments add complexity to trip generation modeling, as combining functions creates overlapping trip purposes and dynamic patterns that conventional databases do not fully capture, particularly in evolving peri-urban areas.

The impact of transportation infrastructure on travel demand is also widely discussed. [Cervero \(2013\)](#) and [Rodrigue \(2020\)](#) highlight that improved accessibility from major infrastructure such as toll roads can induce additional demand and reshape spatial development, introducing externally induced traffic that differs from land-use-based generation.

Several studies also link traffic growth to environmental impacts: increased trip generation raises vehicle-kilometers traveled (VKT), which is directly associated with higher emissions. [Lozano et al. \(2021\)](#) and the [Ministry of Transportation of the Republic of Indonesia \(n.d.\)](#) show that activity-based approaches linking traffic volume with emission factors provide a practical framework for estimating transport-related emissions in rapidly developing areas.

Taken together, this literature reveals a persistent divide: land-use-based models ([Abu-Eisheh et al., 2024](#); [Breški et al., 2025](#); [Institute of Transportation Engineers, 2017](#); [Ortúzar & Willumsen, 2011](#)) and infrastructure-induced demand studies ([Cervero, 2013](#); [Rodrigue, 2020](#))

evolved as separate traditions, leaving their interaction under simultaneous toll-access and mixed-use activation largely unexamined. GFA-based (Breški et al., 2025) and ITE-derived approaches (Abu-Eisheh et al., 2024; Mukherjee & Kadali, 2022), though practical in data-limited settings, remain validated mainly for single-function urban developments, leaving hybrid toll-access-IEA corridors in rural-to-peri-urban transition untested—a gap this study addresses. Likewise, while the traffic–emission link is well established (Lozano et al., 2021; Ministry of Transportation of the Republic of Indonesia, n.d.), applications rarely extend estimation across a multi-decade horizon or couple it with a decomposed, multi-source model. This study bridges these literatures by decomposing demand into three components and linking their 40-year projections directly to VKT-based emission estimation.

RESEARCH METHOD

Building on the reviewed literature, conventional trip generation approaches cannot capture the complexity of peri-urban development, given toll-induced traffic and mixed-use developments such as the IEA. Toll access introduces externally induced traffic, the IEA generates trips from land-use characteristics, and existing traffic reflects socioeconomic baseline growth. This study adopts an integrated framework that decomposes demand into these three components for projection and impact analysis.

Study Area

The study area is at a planned T-intersection that connects the access road for Section 1 of the Yogyakarta–Bawen Toll Road to the existing arterial network along Jl. Tempel–Dekso in Tempel District, Sleman Regency, Yogyakarta—a node where toll-induced traffic is expected to interact with existing local traffic in a predominantly rural setting.

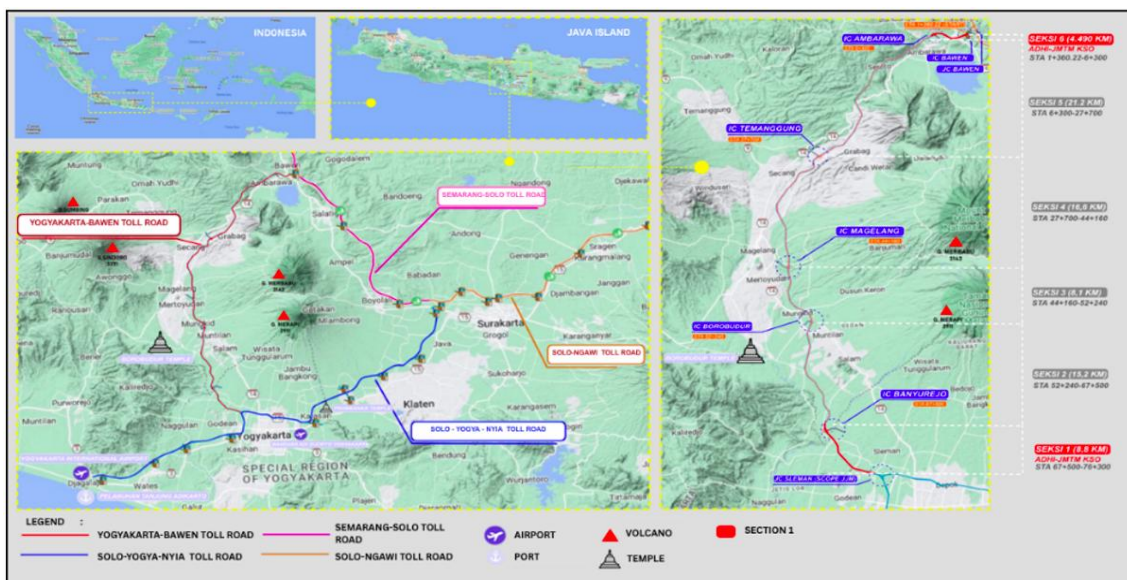


Figure 1. Development Route of Trans Java Toll Road and Yogyakarta-Bawen Toll Road, focusing on Section 1 Sleman-Banyurejo Area

Spatially, the surrounding area within roughly 5 km remains largely agricultural, particularly rice fields, indicating a rural-to-peri-urban transition zone. Despite this rural character, the location is strategically important for its proximity to major tourism corridors, notably the cultural axis connecting the Borobudur and Prambanan Temples, enhancing its potential as a future

activity node under the planned IEA.

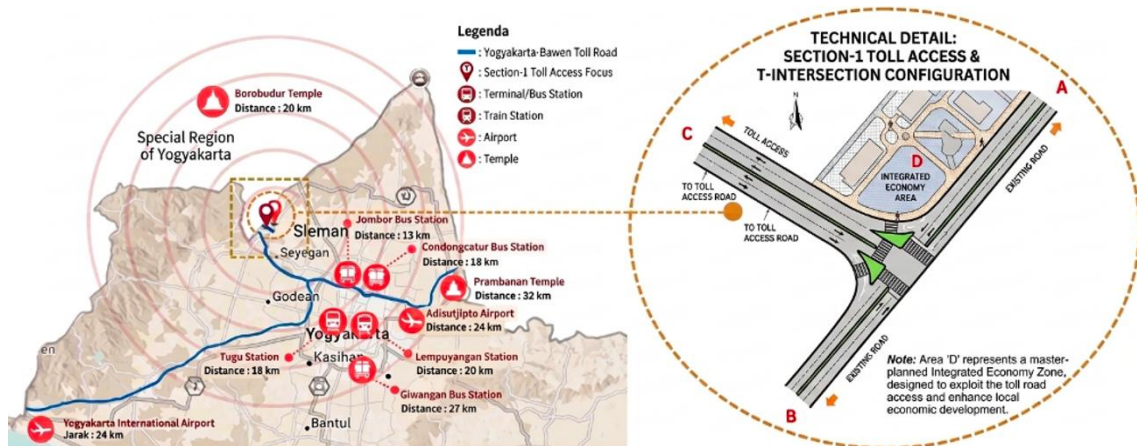


Figure 2. Accessibility Map of Yogyakarta Region and Technical Detail of Section-1 Toll Access with T-Intersection Configuration

From a transportation perspective, the study area is a unique case where three demand sources converge: (i) background traffic, (ii) externally induced toll-access traffic, and (iii) internally generated IEA trips—making it highly relevant for analyzing infrastructure-induced mobility patterns and their environmental implications.

Research Flowchart

To operationalize this framework, the methodology follows a sequential workflow shown in Figure 3: data collection, trip generation analysis, traffic projection, scenario development, and emission estimation. Traffic demand is decomposed into toll-access, IEA-generated, and existing traffic, with each component projected over 40 years and converted to VKT to assess emission impacts and network performance.

Data Collection

The analysis combines primary data (existing traffic volumes from field observations at peak periods) and secondary data: toll traffic forecasts, IEA land-use data (gross floor area, activity capacity), and socioeconomic indicators (population, GRDP) from official statistics. Emission factors and travel distances are adopted from established references to estimate VKT and emissions.

Model Assumptions, Validation, and Limitations of The Estimation Approach

The projection framework relies on several assumptions. First, the 40-year projection assumes that regional growth (population and GRDP) and phased Joglosemar toll activation follow the pessimistic, moderate, and optimistic RTRW trajectories; deviations would proportionally shift projected demand and emissions. Second, IEA trip generation uses an α -factor S-curve model aligned with the Governor of DIY's phased capacity policy (40–60% Years 1–2, 60–80% Years 3–5, full from Year 6), assuming development proceeds as scheduled. Third, because no comparable operational toll-access IEA exists, rates were transferred from the Semarang–Demak case, which may over- or underestimate demand given differences in income, catchment population, and tenant mix. Fourth, emission estimates assume constant fleet-average IVE Model RI factors ($\text{CO}_2 = 187 \text{ g/km}$; $\text{CO} = 12.5 \text{ g/km}$), which do not account for future efficiency gains or electrification, making the figures a conservative upper bound. Projections were cross-checked against corridor-level

AADT projections, showing convergent trends, though no external validation against post-opening counts was possible since the toll section and IEA are not yet operational.

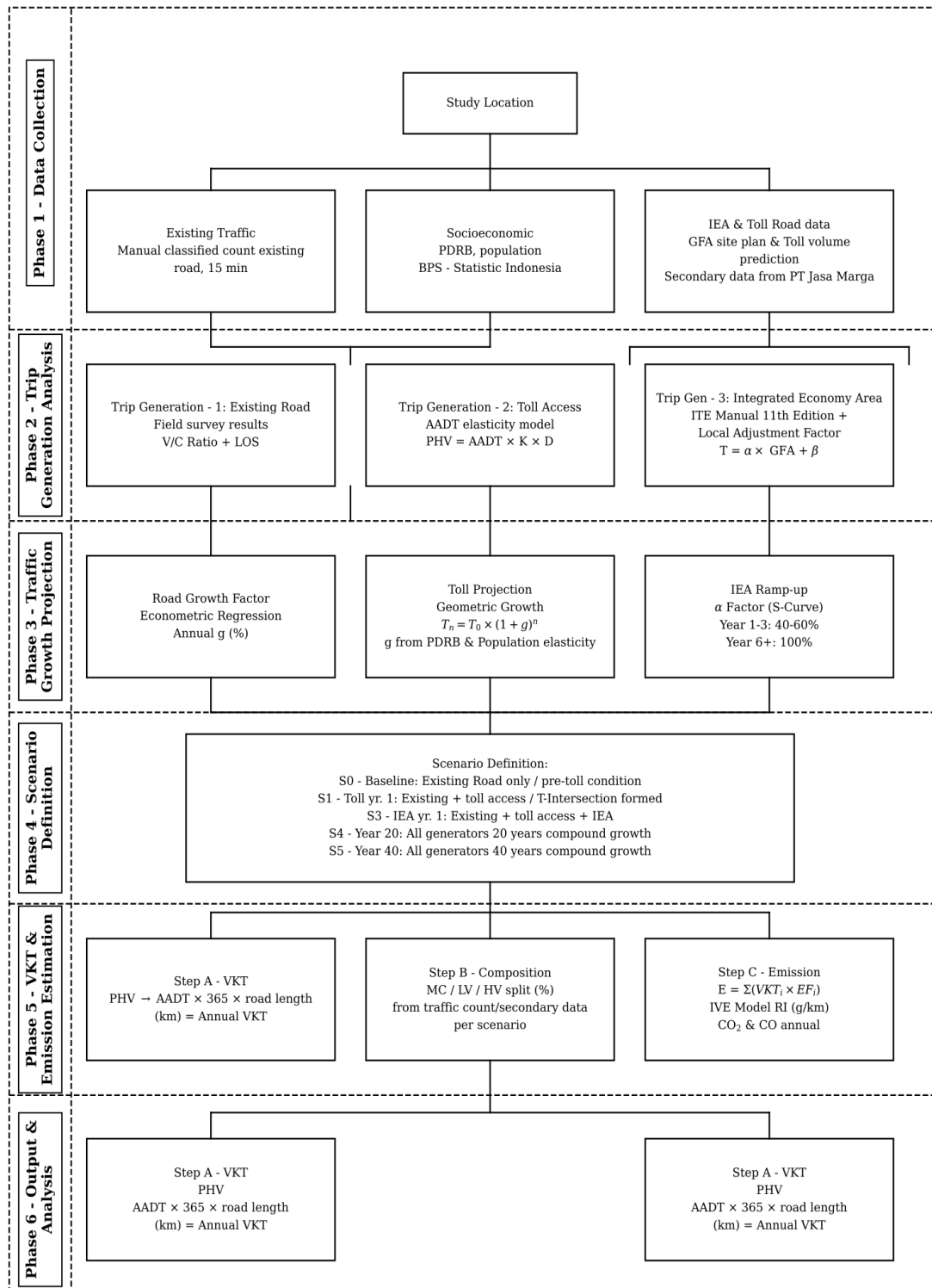


Figure 3. Research workflow for trip generation, traffic projection, and emission estimation under toll access and IEA development scenarios

FINDINGS AND DISCUSSION

Traffic volume projections at the Banyurejo T-Intersection, demand estimates for Toll Road Section 1, IEA-induced trip rates, and associated emission loads were derived through a structured analytical sequence and are reported below to show the magnitude and environmental significance of infrastructure-induced demand growth.

Results

Traffic Volume Projection at the Banyurejo Toll Access Intersection (Trip Generation — Toll Access Component)

The four-step demand model yields intersection-level turning movement predictions for the Banyurejo T-intersection, as reported in Table 1; Figure 4 illustrates the corresponding trends in flow and saturation.

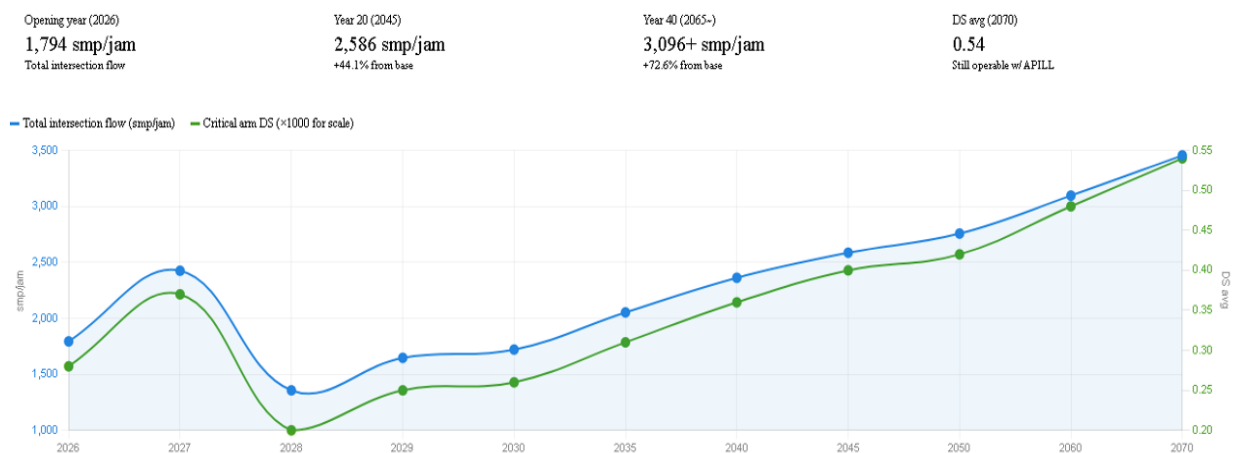


Figure 4. Projection of total intersection traffic flow and degree of saturation (DS) at the Banyurejo toll access from 2026 to 2070

Table 1. Projected Traffic Volume at Banyurejo Access Intersection

Year	A→C	A→B	B→A	B→C	C→B	C→A	Total	DS avg
2026	227	469	478	207	211	202	1,794	0.28
2030	196	489	486	185	187	178	1,721	0.26
2035	244	564	565	228	231	221	2,053	0.31
2040	286	638	640	268	271	259	2,362	0.36
2045	318	689	693	297	301	288	2,586	0.40
2050	339	732	732	321	324	309	2,757	0.42
2060	389	808	812	365	369	353	3,096	0.48
2070	443	884	891	415	420	402	3,455	0.54

The Banyurejo Access Junction, a planned T-intersection along Jalan Tempel–Dekso, interfaces Section 1 of the Yogyakarta–Bawen Toll Road (8.25 km) with the existing rural arterial network. Traffic volume was projected over 40 years (2026–2070), with major approaches upgraded from a 2/2 undivided (7 m) to a 6/2 divided cross-section (21 m).

At the opening year (2026), total intersection flow is estimated at 1,794 pcu/hour. The dominant movements (A→B and B→→B and B→A) represent through traffic along the existing corridor, showing traffic is initially governed by existing flows while toll-access movements remain

emerging. Average DS is 0.28, with the toll ramp as the critical approach (DS = 0.35), well below the acceptable threshold and indicating the earliest concentration of toll-related demand.

By 2070, total intersection flow is projected to rise from 1,794 to 3,455 pcu/hour, a 92.6% increase (1.6% average annual growth). Short-term fluctuations reflect phased toll development before the corridor reaches equilibrium. In the medium term (2045), traffic reaches 2,586 pcu/hour (DS = 0.40), rising to about 3,096 pcu/hour by 2065 (DS = 0.48) and 3,455 pcu/hour by 2070 (DS = 0.54); toll-ramp queue length grows from 26.42 m to 47.05 m over the period.

Despite substantial growth, the intersection remains operationally stable under signalized control (APILL), though the toll ramp consistently represents the critical approach, indicating future risks are likely localized there rather than system-wide.

Traffic Volume Projection for Toll Road Section 1 (Trip Generation — Toll Road Component)

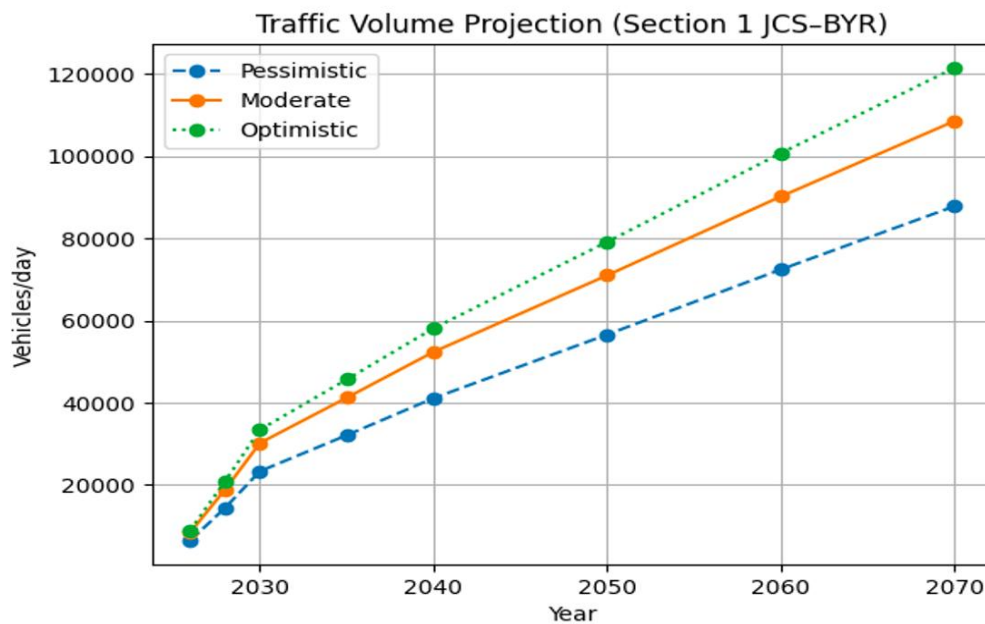


Figure 5. Projected Annual Average Daily Traffic (AADT) growth for Section 1 (JC Sleman–IC Banyurejo) of the Yogyakarta–Bawen Toll Road under pessimistic, moderate, and optimistic scenarios, 2026–2070

Table 2. Traffic Volume Projection for Section 1 (JCS–BYR) of the Yogyakarta–Bawen Toll Road (2026–2070)

Year	Pessimistic	Moderate	Optimistic	Growth (Mod.)
2026	6,454	8,464	8,990	—
2028	14,405	18,851	20,877	+123%
2030	23,294	30,167	33,398	+256%
2035	32,078	41,201	45,653	+387%
2040	41,092	52,359	58,106	+519%
2050	56,585	71,010	79,149	+739%
2060	72,425	90,197	100,738	+966%
2070	87,824	108,562	121,524	+1,183%

The macroscopic demand analysis for Section 1 of the Yogyakarta–Bawen Toll Road (JC Sleman–IC Banyurejo, 8.25 km) was conducted under three socioeconomic growth scenarios—

pessimistic, moderate, and optimistic—calibrated using regional PDRB growth, RTRW land-use plans, and phased Joglosemar corridor activation.

Under the moderate (base-case) scenario, AADT is projected to rise from 8,464 vehicles/day in 2026 to 30,167 by 2030 after full corridor activation in 2028, and to 108,562 by 2070 (1,183% cumulative growth). This transforms Banyurejo from a temporary terminus into an integral segment of the continuous Joglosemar corridor.

Scenario divergence widens over time: the optimistic scenario reaches 121,524 vehicles/day and the pessimistic 87,824 by 2070, a difference of about 38%, providing the basis for the IEA-induced trip generation analysis.

Trip Generation Estimation for the Integrated Economy Area (IEA) — Application of the Comparative Reference Method

Given the absence of an operational IEA adjacent to a comparable toll access, trip generation for the Type-A IEA was estimated using a comparative case approach (Mudiyono & Asfari, 2021), drawing on the Semarang–Demak Toll Road arterial access, the closest comparable case, as both involve a new toll gateway generating through traffic and land-use-induced demand. The planned Banyurejo IEA also has dual access from the toll road and the existing network, so its trip generation includes both toll users and visitors from the surrounding road network.

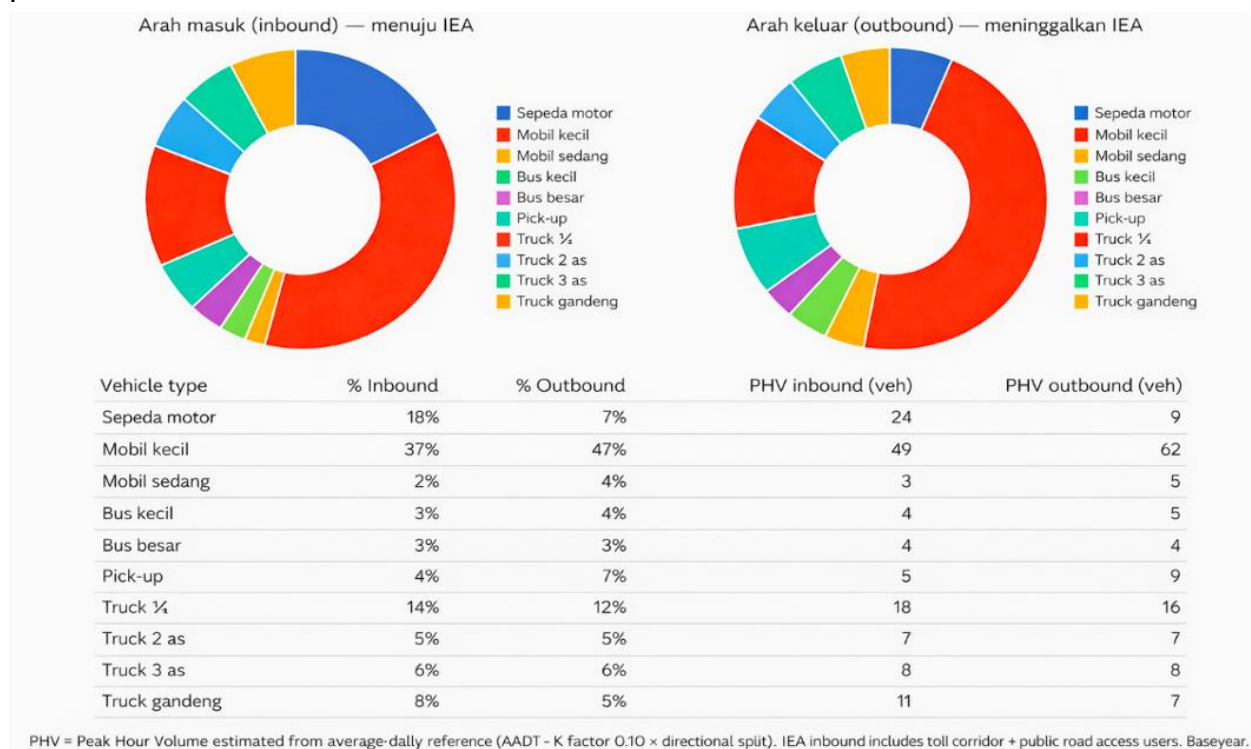


Figure 6. Vehicle composition and estimated trip generation of the Banyurejo IEA based on primary traffic survey data from the toll access intersection

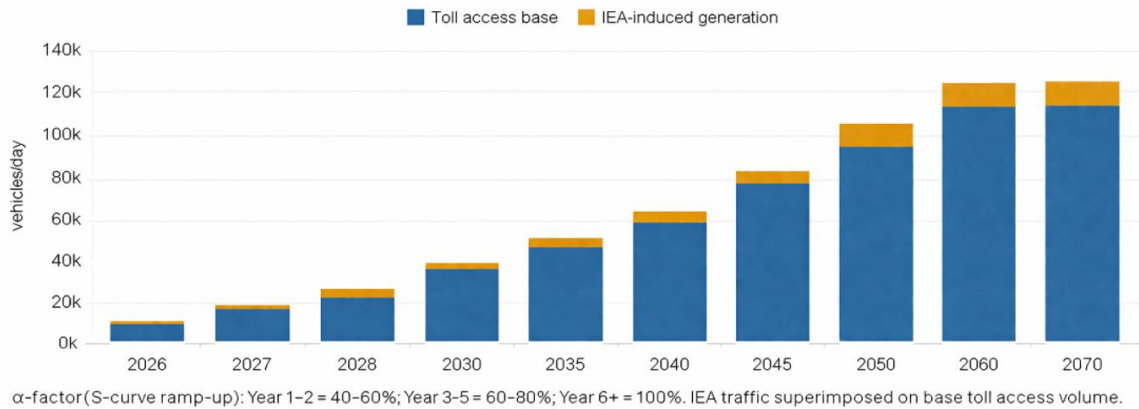


Figure 7. Projected IEA trip generation (vehicles/day) under a moderate S-curve ramp-up scenario, showing additional IEA-induced traffic on top of base toll access volumes from 2026 to 2070

The reference composition is dominated by light vehicles (cars: 37% inbound, 47% outbound) and motorcycles (18%/7%), while goods vehicles—trucks $\frac{3}{4}$ (14%/12%) and articulated trucks (14% inbound)—reflect logistics function, typical of a peri-urban mixed-use corridor where light vehicles represent IEA visitors and toll users and heavy vehicles support economic activity.

IEA trip generation was projected using an α -factor S-curve model per Governor of DIY policy (40–60% Years 1–2, 60–80% Years 3–5, full from Year 6). IEA-generated traffic rises from about 1,016 vehicles/day in 2026 to 5,059 by 2030 and 13,027 by 2070; combined with base toll traffic, total demand reaches 121,589 vehicles/day under the moderate scenario.

Emission Estimation from Projected Trip Generation

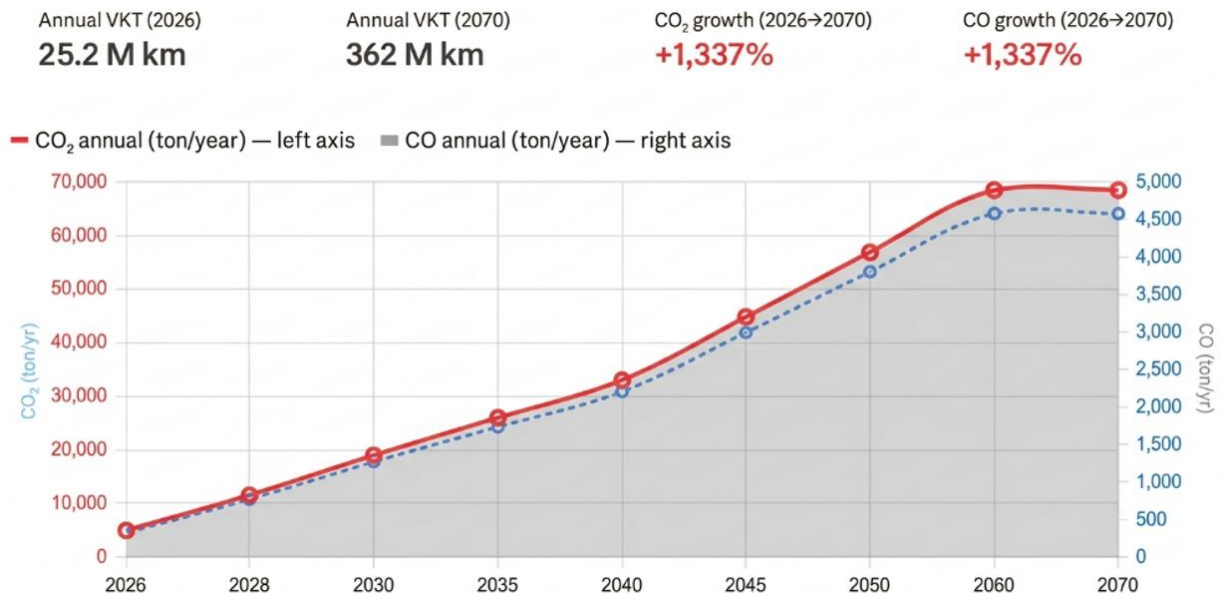


Figure 8. Emissions projection vs. VKT growth. Comparative annual CO₂ and CO output (2026–2070) showing a 1,337% increase in impact

Table 3. Annual projection of traffic volume, VKT, and emissions (2026–2070)

Year	Total veh/day	Annual VKT (km/yr)	CO ₂ (ton/yr)	CO (ton/yr)	CO ₂ index
2026	8,870	26.7 M	4,995	334	100
2028	20,648	61.0 M	11,671	773	232
2030	33,787	101.7 M	19,026	1,272	381
2035	46,145	139.0 M	25,984	1,737	520
2040	58,642	176.6 M	33,022	2,207	661
2045	70,531	230.5 M	44,784	2,994	897
2050	101,021	304.2 M	66,885	3,802	1139
2060	121,589	366.1 M	68,467	4,577	1371
2070	121,589	366.1 M	68,467	4,577	1371

Vehicular emission estimation follows three steps: (A) annual VKT from AADT and segment length; (B) vehicle fleet composition from primary survey data; and (C) emission quantification using IVE Model RI factors, expressed as

$$E = \sum_i (VKT_i \times EF_i)$$

where i denotes vehicle class.

Annual VKT for the Banyurejo corridor (8.25 km) rises from 25.2 million km/year in 2026 to about 362 million by 2070, a 14.4-fold increase. Using fleet-average IVE Model RI factors (CO₂ = 187 g/km; CO = 12.5 g/km), CO₂ emissions rise from about 4,713 tonnes/year in 2026 to 67,774 by 2070 (+1,337%), while CO rises from 315 to 4,527 tonnes/year. A pronounced acceleration occurs between 2026 and 2030, when full corridor opening and IEA ramp-up quadruple annual CO₂ emissions (4,713–19,011 tonnes/year)—the most significant transition, as agricultural land undergoes rapid, irreversible transformation.

Discussion

The integrated analysis reveals a clear demand amplification mechanism from co-locating a toll access node and an IEA in a previously low-intensity rural corridor. While baseline toll traffic grows about 2.1% annually, IEA-generated trips drive much sharper growth in 2026–2035, with intersection volumes rising about 14.4% annually, indicating conventional reactive capacity expansion is insufficient when multiple generators activate simultaneously.

Despite this surge, the intersection maintains acceptable performance, with DS below 0.54 over 40 years given planned upgrades. Yet stable traffic performance contrasts sharply with environmental impact: emissions are projected to reach about 67,774 tonnes of CO₂ and 4,527 tonnes of CO by 2070, with the most critical increase during early years—highlighting the need to integrate VKT-based emission modeling into impact assessments.

The IEA's dual-access characteristic also extends traffic impacts beyond the intersection, requiring corridor capacity planning and multimodal accessibility; the phased S-curve development enables adaptive investment, while multimodal and low-carbon strategies are essential to reduce long-term emission intensity.

These findings align with international evidence on infrastructure-induced demand. [Cervero's \(2013\)](#) and [Rodrigue's \(2020\)](#) observations that improved accessibility induces additional demand and reshapes development are corroborated at Banyurejo, where combined

toll-access and IEA trip generation accelerate growth well beyond baseline trends. The fourteen-fold VKT increase and CO₂ trajectory also echo findings from Trans-Java corridors (Aditya & Husna, 2022; Shofy & Wibowo, 2023), extending that evidence by quantifying emissions over a 40-year horizon rather than cross-sectional indicators. Compared with frameworks in other motorizing regions (Lozano et al., 2021; Ministry of Transportation of the Republic of Indonesia, n.d.), which link static volumes to emission factors, this decomposition offers a dynamic, multi-source view that reflects the compounding effect of simultaneous activation. Practically, similar toll access-IEA assessments elsewhere should not rely solely on intersection-level indicators, since acceptable performance, as at Banyurejo, can mask a much larger environmental burden; the framework proposed here offers a replicable method to anticipate and mitigate it.

CONCLUSIONS

This study demonstrates that integrating toll access infrastructure with an Integrated Economic Area (IEA) in a peri-urban rural corridor significantly transforms both traffic dynamics and environmental conditions. Multiple trip-generation sources create a strong demand-amplification effect, particularly early on, when traffic growth accelerates beyond conventional projections. Despite this, the Banyurejo T-intersection maintains stable long-term performance with appropriate geometric design and signal control, indicating that early infrastructure readiness is essential.

However, traffic performance alone is insufficient to measure infrastructure success: the projected emissions increase shows infrastructure-induced development can rapidly transform a low-intensity rural corridor into a high-emission environment, highlighting the need to expand impact assessments with VKT-based emission modeling.

From a planning perspective, the IEA's dual-access characteristic extends impacts beyond the project boundary, requiring integrated corridor planning and multimodal strategies. The phased demand growth identified here also supports adaptive, sequential investment, letting decision-makers respond to actual demand. This study shows that successful toll corridor development depends on managing induced demand, mitigating environmental impacts, and integrating land-use and transport planning.

LIMITATIONS & FURTHER RESEARCH

This study has several limitations. First, the 40-year projections rely on pessimistic, moderate, and optimistic PDRB/RTRW trajectories; actual growth may deviate due to macroeconomic shocks or phasing delays, shifting the magnitude and timing of demand and emissions. Second, emission estimates use constant fleet-average IVE Model RI factors and do not account for future efficiency gains or electrification, so the trajectory is a conservative upper bound. Third, since no comparable operational toll-access IEA exists, rates were transferred from the structurally similar Semarang-Demak case; differences in income, catchment, and tenant composition remain an unresolved uncertainty. Fourth, the analysis covers a single T-intersection and corridor segment, so findings may not transfer to corridors with different geometry or growth dynamics. Future studies should incorporate dynamic traffic assignment, modal shift analysis, and alternative emission scenarios accounting for electrification and evolving standards.

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