Eduvest – Journal of Universal Studies
Volume 6 Number 1, January, 2026
p- ISSN 2775-3735- e-ISSN 2775-3727

The Environmental Impacts of the Trans-Java Toll Road Infrastructure Project

Ririn Yuliatiningsih*, M. Halley Yudhistira
Universitas Indonesia, Indonesia
Email: ryuliatiningsih@gmail.com*

ABSTRACT

The research aims to analyze the operational impact of the Trans Java toll road on environmental quality in districts and cities on the island of Java during 2012–2024. Three environmental indicators—Air Quality Index (IKU), Environmental Quality Index (IKLH), and carbon emissions—are used. The method employed is Difference-in-Differences with Two-Way Fixed Effects regression and Dynamic Analysis. Nationally, the operational impact of toll roads does not show significant effects on IKU, IKLH, or carbon emissions, indicating that environmental impacts are contextual. Spatial analysis revealed a significant decline in air quality in Central Java, the main corridor of the Trans Java network, consistent with the theory of network centrality, in which high-traffic areas bear greater environmental externalities. Topographic characteristics, such as basins and valleys, exacerbate environmental vulnerability by limiting the spread of pollutants. These findings emphasize the need for the government to consider spatial heterogeneity and topographic variables in the construction of toll roads. This research opens opportunities for further studies on the environmental impact of toll roads over a longer period and with a more detailed approach.

KEYWORDS *infrastructure, trans java, difference in difference, two-ways fixed effect, air quality index*

INTRODUCTION

The construction of toll roads is one part of infrastructure development that functions to improve regional connectivity, facilitate the distribution of goods and services, and encourage regional economic growth (Berawi et al., 2016; Situmorang et al., 2025). Based on Law Number 38 of 2004 concerning Roads, the definition of a toll road is a public road that is part of the national road network system and is intended for traffic with the imposition of tolls in exchange for its use. Toll roads are developed to support efficient mobility and accelerate equitable development between regions (Ministry of PUPR, 2019).

Based on Government Regulation No. 23 of 2024 concerning Toll Roads, the construction of toll roads is intended as part of an efficient, safe, and sustainable national transportation system. The construction of toll roads must pay attention to the balance of environmental, social, and economic aspects. The concept of "Sustainable Road Construction" is integrated in every stage of construction and management. In terms of technical and environmental aspects, toll roads must meet technical standards for safety, comfort, and environmental aesthetics (Articles 6–9), rest areas must pay attention to environmental sustainability and access for MSMEs (Articles 9–10), and must go through environmental impact analysis (EIA) in accordance with laws and regulations (Article 37).

The length of toll roads in Indonesia, which is located on five major islands, namely Java, Sumatra, Kalimantan, Sulawesi, and Bali, has reached 2,893.01 km and is managed by 52 Toll Road Business Entities (BUJT). The longest toll road section is located on the island of Java, mainly the Trans Java toll road (1,065.49 km), followed by the island of Sumatra with trans Sumatra (941.75 km) and Kalimantan Island 97.27 km.

On the island of Java, the construction of the Trans Java Toll Road is tangible evidence of infrastructure development that has succeeded in connecting access between major cities. The construction of the Trans Java toll road is one of the National Strategic Projects that aims to improve connectivity between regions on the island of Java. The Trans Java toll road connects the western end to the eastern tip of the island of Java, has been carried out since 1978, and the opening of toll roads has been carried out in stages.

In 2019, the Average Daily Traffic (LHR) data of the Trans Java toll road was 1.1 million vehicles per heart, up 3.23% from 2018. Even in 2025, the number of vehicles passing on the Trans Java toll road will increase by 10% on D-10 Eid. The increased access between these major cities has lowered travel time and the cost of distributing goods, which in turn has increased regional economic activity. However, the economic development produced through infrastructure development also has implications for physical and social environmental conditions. Increasing industrial activity and the increasingly high volume of motor vehicles have the potential to reduce environmental quality through air pollution, ecosystem degradation, and conversion of productive land into built-up areas (Rodrigue et al., 2020).

Several international and national studies show mixed results regarding the impact of toll road infrastructure development. On the one hand, toll road construction provides economic benefits through increased accessibility, business activities, and travel time efficiency (Muyasaroh & Herlina, 2022; Sumaryoto, 2010), but on the other hand, it has negative impacts on the environment, such as air pollution, noise pollution, agricultural land degradation, land conversion, community eviction, water quality degradation, ecosystem damage, and reduced water infiltration (Khasanah et al., 2017; Dewi et al., 2025; Masrida, 2024; Stuart et al., 2025; Hafnidar & Azlan, 2020; Hidayat et al., 2020).

International studies show contradictory results, some studies have found that improving transportation infrastructure can lower local air pollution and provide environmental health benefits (Sun et al., 2019; Shuhua Xu, 2023; Ye & Li, 2024; Zhi Luo et al., 2018; Harleman, 2023; Lee et al., 2023), while other studies have shown increased carbon emissions, fine particles, and health risks due to traffic growth (Sharif & Tauqir, 2021; Zhang et al., 2013; Liu et al., 2021; Zhang & Batterman, 2013; Xie et al., 2017).

In the context of Indonesia, although there are a number of studies on the economic impact of toll road construction, research on environmental impacts is still limited. Most of these studies use a qualitative approach through literature studies or quantitative through surveys and interviews. There has not been a study that has analyzed the impact of toll road construction comprehensively using secondary data and at the same time considering the spatial dimension. This approach is important to produce more targeted policy recommendations. Thus, there is a clear research gap, namely the need for research that integrates spatial environmental analysis to capture regional heterogeneity and topography in order to comprehensively understand the consequences of toll road construction so that it can produce targeted policy recommendations.

Infrastructure based on the World Bank (1994) is divided into three, namely (i) Economic infrastructure, which is the physical infrastructure needed to support economic activities, such as basic water services, telecommunications, roads, dams, and the transportation sector; (ii) Social infrastructure, including education, health, housing and recreation (iii) Administrative infrastructure, including law enforcement, administrative control and coordination.

Toll roads are one of the infrastructures built by the government to facilitate inter-regional transportation. Based on Government Regulation (Government Regulation No. 15 of 2005), toll roads are national roads that are part of the road network and must be borne by their users. The development of toll road infrastructure can have an impact on the surrounding area that it passes. The Trans Java toll road is one of the toll roads in Indonesia. The Trans Java Toll Road is a 1,167 km expressway connecting Serang, Banten, and Banyuwangi, East Java.

The construction of the Trans Java Toll Road is a form of regional autonomy that aims to improve the welfare of the population in each region. The regional autonomy policy as a stage of assistance, local governments as assistance in achieving the goal of toll road construction, utilizing the advantages of each region in accordance with Law Article 18 paragraph 6 concerning the authority of the central government to establish regional regulations and other regulations, to implement autonomy and the level of assistance (Muyasaroh & Herlina, 2022).

Government Regulation No. 23 of 2024 provides a clear regulatory framework that the construction of toll roads must be in line with the principles of environmental conservation. However, in practice, implementation often faces challenges such as weak monitoring of EIA (Environmental Impact Analysis), increased pollution due to high traffic, and land use changes that have not been fully controlled.

Each Trans Java toll road from Merak to Banyuwangi is required to identify and minimize potential impacts, including: increased air pollution due to vehicle volume, conversion of agricultural land and forests, disturbances to ecosystems and biodiversity, and changes in water quality. This regulation explicitly links the responsibility for toll road construction with efforts to maintain the quality of the environment in the affected areas. The implementation of Government Regulation No. 23/2024 is very important considering the diverse ecological characteristics of the area that is passed, ranging from industrial estates in Cilegon, agricultural centers in Brebes, to mountainous and coastal areas in East Java.

The concept of Road Ecology introduced by Forman and Alexander (1998) describes the reciprocal relationship between road infrastructure and the natural environment, focusing on the ecological impact of roads on ecosystems, hydrology, and biodiversity. Forman and Alexander identified various major impacts of the road, such as habitat fragmentation, disruption to species migration, increased wildlife mortality due to collisions, and changes in water flow patterns and hydrological quality that affect the nutrient cycle and productivity of ecosystems. The concept of Road Ecology is an important basis in sustainable infrastructure planning, encouraging the implementation of environmentally friendly road design.

The modern paradigm demands sustainable infrastructure development, which is infrastructure that not only pursues economic growth, but also takes into account social and environmental impacts. According to the World Bank (2020), sustainable infrastructure must meet three main pillars: economic efficiency, social inclusion, and environmental sustainability. Therefore, the study of toll road construction cannot be separated from the analysis of its ecological and social impacts.

Air quality is one of the important indicators in assessing the physical condition of the environment. The construction of toll roads, with intensive construction activities and an increase in the volume of motor vehicles, can result in significant exhaust emissions. These emissions are made up of various air pollutants such as Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), and fine particles (PM10 and PM2.5). These pollutants have the potential to pollute the air and negatively impact human health and ecosystems. Air quality is an example of a public good which is a non-rival and non-excludable item. Environmental goods are typically non-market goods, including clean air, clean water, rivers, mountains, forests, and beaches. The item will have negative externalities if the quality is poor (Pindyck, R. S., & Rubinfeld, D. L., 2018).

In general, based on the results of several studies on infrastructure development in the form of toll roads have negative effects on the environment as the results of research (Khasanah et al., 2017) which stated that the construction of the Solo-Kertosono toll road increases air pollution, the construction of toll roads although it shortens travel time and increases business activities but causes losses such as reduction of agricultural land and environmental degradation (Sumaryoto, 2010).

The construction of toll roads provides economic benefits (accessibility, business opportunities), but there is a lack of anticipation (compensation, noise/air pollution) (Muyasaroh & Herlina, 2022), a decrease in air quality (Dewi et al 2025), there is also an increase in noise intensity above the quality standard and indications of water pollution by domestic waste (Masrida, 2024), Apriliyaningsih et al, (2025) negative impacts that arise such as community eviction, changes in lifestyles, pollution, ecosystem damage, and land use change. The construction of toll roads has a significant impact on the environment, especially on declining air quality, increased pollution, potential landslides due to tree felling, the occurrence of solid waste and B3, reduced water infiltration, and damage to protected forests (Hafnidar A., & M. Azlan, 2020), the existence of the Trans Java toll road in the Pemalang-Batang area triggers an increase in noise pollution and a decrease in agricultural land (Hidayat et al, 2020).

Meanwhile, some studies abroad show quite mixed results. Based on studies in Pakistan, it shows that there will be a trade-off between infrastructure expansion and environmental quality mainly increased carbon emissions (Sharif & Tauqir, 2021), increased concentration of fine particles in areas near highways (< 300 m) Zhang et al. (2013), construction of new roads shows a significant increase in $PM_{2.5}$ (Liu et al., 2021), increased traffic significantly increases emissions and the risk of morbidity and mortality (Zhang & Batterman, 2013), the development of transportation infrastructure significantly increases carbon emissions and intensity, especially in large and medium-sized cities (Xie et al., 2017).

Several studies have given different results, improving urban transportation infrastructure has an impact on reducing urban haze pollution through transmission of increased public transportation (Sun et al., 2019), increasing the overall road area ratio reduces air pollution (Shuhua Xu, 2023) due to reduced traffic congestion, increasing vehicle speed, and reducing emissions per unit of travel, road infrastructure construction significantly reduces air pollution local (Ye & Li., 2024), cities with more dense road networks tend to have better air quality due to the even distribution of traffic (Luo et al. (2018), road infrastructure can provide environmental health benefits (lowering air pollution), although it is necessary to take into account the temporary adverse impacts during the construction period (Harleman, 2023), the opening of high-speed rail lines, there has been a significant reduction in motor vehicle-related pollutants, especially CO and PM2.5, (Lee et al, 2023).

This study also aims to identify the extent to which the application of sustainable development principles and environmental policies in the planning, construction, and operation process of the toll road. The benefits of this research are expected to provide academic contributions in the form of enriching infrastructure and environmental studies, as well as being evaluative material for the government, toll road managers, and related stakeholders in formulating environmental impact mitigation policies that are more effective, sustainability-oriented, and oriented towards a balance between economic development, transportation mobility, and environmental conservation.

RESEARCH METHOD

This study examines how toll road infrastructure development affects the quality of the environment in districts/cities on the island of Java, hypotheses that will be tested in this study: (1) The operation of the Trans Java toll road has a significant negative effect on the IKLH of the district/city passed by the Trans Java Toll Road (Tanda -), (2) The operation of the Trans Java toll road has a significant negative effect on the KPI of the district/city passed by the Trans Java Toll Road (Sign -), (3) The operation of the Trans Java toll road has a significant negative effect on the Carbon Emissions of regencies/cities passed by the Trans Java Toll Road (Sign +), (4) The operation of the Trans Java toll road has a significant negative effect on the quality of the environment in the main corridor of the Trans Java (Central Java) toll road traffic flow, and (5) The operation of toll roads has a significant negative effect on the quality of the environment in areas that have basin and valley topography. The following is a conceptual diagram of the relationship between toll road construction and the impact on environmental aspects:

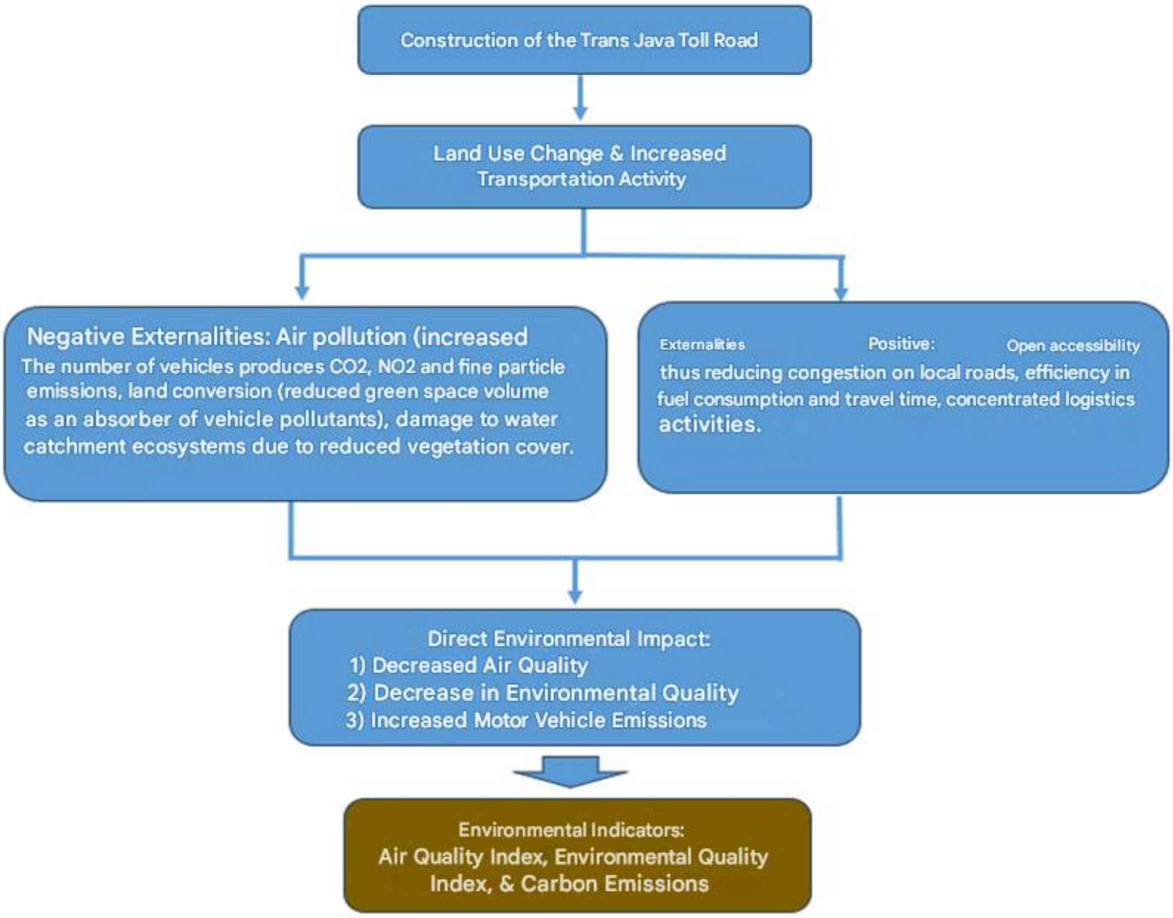


Figure 1. Conceptual framework of the research

The models used in the study are as follows:

$$Y = \beta 0 + \beta 1\ Dit + X'_{it}\gamma + \alpha t + \alpha i + \varepsilon it. \quad (1)$$

Where, **Yit** is the Environmental Quality Index/ Air Quality Index/ Carbon Emission Index of the district/city i in year t. Dit is a variable of interest/dummy variable/treatment variable which is worth 1 after the Trans Java toll road operates in the district/city i in year t, and 0 if not, β1 is the coefficient that shows the change in the impact of the operation of the Trans Java toll road on environmental aspects (IKU/IKLH/carbon emissions) between the treatment group (districts/cities that are passed) and the control group (districts/cities that are not passed), Xit is a control variable that is considered to be able to affect the results, where to reduce the omitted variable bias, αi is fixed effect regency/town, εit = error term.

The research will use a quantitative approach with a quasi-experimental design, namely measuring the causal impact of the construction of the Trans Java Toll Road on the quality of the inter-regional and inter-temporal environment. The main method used is Difference-in-Differences (DiD) Two-Way Fixed Effect (TWFE), used to neutralize the bias that arises from regional factors and changes in years. This method refers to the development of the model by Goodman-Bacon (2021). The researcher will also conduct dynamic analysis to complement the empirical analysis method to measure the impact of an event on an outcome variable in a certain period of time (pre and post event).

Outcomes related to environmental aspects to be studied are IKU, IKLH, and carbon emissions in areas that have been passed by toll roads with changes that occur in areas that have not been passed, before and after the toll operational period. IKLH is a composite value of the Water Quality Index, Air Quality Index, Land Quality Index, and Seawater Quality Index. IKU is a measure used to assess air pollution which is calculated using two parameters, namely NO2 and SO2. Carbon emissions are the process of releasing carbon dioxide (CO2) into the earth's atmosphere caused by various natural factors and human activities.

GDP per capita is one of the economic indicators in economic development, as a benchmark for macro community prosperity and development success. GDP per capita is obtained by dividing GDP by the number of people in the middle of the year. Population density is calculated based on the number of inhabitants divided by the area of the area, the unit used is the population per square kilometer. This indicator is used to measure the distribution of the population in an area**.**

Angrist and Pischke (2009), explained that the approach is based on the concept of counterfactual which can estimate historical changes that occur in various areas that have been passed by toll roads and have not been passed because the development process has not been completed. The methods are a control group and a treatment group. Of the 119 districts/cities on the island of Java spread across 6 provinces, there are 44 districts/cities that are passed by the Trans Java toll road (treatment area), and as many as 75 districts/cities that are not passed by the Trans Java toll road (control area). This research is quantitative research compiled using secondary data. The data period used is from 2012 to 2024 with an annual data frequency. The data details consist of air quality index data, carbon emissions, environmental quality index, GDP per capita, and population density in each district/city on the island of Java.

RESULTS AND DISCUSSION

Sample Description

The data was processed using the Stata19SE program. The data is converted using natural logarithms (ln) to produce stationery and smooth regression. Table 1. presents descriptive statistical results of several key variables used in the analysis. In general, the KPI and IKLH variables tend to have small variations. Meanwhile, the variables of GDP per capita, carbon emissions, and population density show significant disparities.

The Impact of the Trans Java Toll Road Based on Regression Results

Regression was carried out in stages on each outcome through five model specifications as a robustness check with the addition of control variables gradually. The fourth model adds interaction between the dummy of the area through which the toll road passes and the dummy of Central Java Province to identify the heterogeneous effect of toll road construction in the region, separate from the general impact nationally. In the fifth model, interaction with the topographic characteristics of basins and valleys is carried out to capture spatial variations influenced by the physical conditions of the region. This phased approach allows for more detailed impact analysis to support the formulation of more targeted policy recommendations.

Impact on the Air Quality Index (ICI)

The estimated results show that the policy of operating the Trans Java toll road for regencies/cities passed by the Trans Java Toll Road tends to have a lower KPI value of around 0.4-0.5 percentage points compared to areas that are not passed by toll roads even though the results are not statistically significant. The results of the spatial interaction estimate showed that the impact on districts/cities in Central Java significantly reduced the KPI by 26.07 percentage points compared to areas in Central Java that were not passed by tolls, and other provincial areas that were passed by tolls, with a significance level of 1%. The coefficients obtained are quite large and negative, showing the existence of structural characteristics of Central Java that are different from other provinces when toll infrastructure is operating. Possibilities that affect these results include the dominant influence of labor-intensive industries that are quite sensitive to logistical changes, Central Java as a Trans-Java logistics corridor with a large volume of heavy vehicles that produce PM2.5 and PM10 particulates that can reduce KPIs, the existence of toll roads diverting pollution from big cities to previously cleaner routes because Central Java has many toll roads that pass through rural areas or semi-urban.

The negative externality felt by the Regency/City in the Central Java region with the construction of the toll road affirms the network[1] theory that Central Java has degree centrality because it occupies a strategic position on the Trans Java toll road because it is geographically located in the middle of Java Island and is the main connecting area between the western region (DKI Jakarta, Banten, West Java) and the eastern region (East Java). The high centrality of Central Java is reflected in the number of toll roads that pass and are connected in this region, such as the Semarang-Batang, Batang-Pemalang, Pemalang-Pejagan, Solo-Ngawi, and Semarang-Solo toll roads, which make Central Java the main transit node in logistics and mobility flows between regions.

Table 2. The Impact of the Operation of the Trans Java Toll Road on the Air Quality Index, base results

Variable	(1)	(2)	(3)	(4)	(5)
District/Town Passed	-0.441	-0.501	-0.430	5.062	7.621
	(6.151)	(6.190)	(6.320)	(4.444)	(6.434)
Ln PDRB per capital		2.836	3.391	6.617	3.631
		(11.145)	(10.495)	(10.508)	(10.629)
Ln Density			1.043	2.407	0.167
			(6.645)	(6.702)	(6.637)
Central Java Interaction				-26.071***	
				(5.364)	
Topographic Interaction					-13.822
					(9.859)
District/Town Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes	Yes
Observations	379	379	379	379	379
R^2 (within)	0.541	0.541	0.541	0.549	0.544

In addition, Central Java as a route passed by most vehicle flows on the island of Java considering that long-distance traffic flows, especially heavy logistics vehicles and freight transportation, will pass through Central Java as the shortest route for cost efficiency. This condition causes the accumulation of traffic vomes so that traffic concentration in areas with high centrality has the potential to increase harmful particulates that negatively impact KPIs in Central Java.

From the perspective of closeness centrality, Central Java has a high level of affordability to the main economic points on the island of Java, so the time and cost of access are relatively lower. This condition encourages an increase in derivative economic activities around toll

[1] Freeman, L. C. (1979)

corridors, such as industrial estates, warehousing, and rest areas. Nevertheless, the increase in such activity will encourage the intensification of the use of motor vehicles and the growth of built-up areas, which in turn will increase the pressure on local air quality.

In terms of regional topography, there are several toll road sections in Central Java that pass-through valleys and basins such as the Salatiga-Boyolali, Semarang-Ungaran sections which cause the wind to be trapped in the basin and cause slower dispersion of pollutants which causes lower KPIs. This is reflected in the results of the regional topography interaction (model 5) that districts/cities with basin and valley topography have a lower KPI of 13.8 percentage points compared to other regions, although not statistically significant.

Impact on the Environmental Quality Index (IKLH)

In model 4, a significant decrease in IKLH has been found by 4 percentage points (significance level at 1%). This indicates that the construction of toll roads can cause pressure on the quality of the environment in the regency/city area that the toll road passes through compared to other regencies/cities that are not passed. The negative impact of toll roads on IKLH became real and significant after the specific effects of Central Java were separated from the national average effects. The coefficient of the district/city passed with a negative and significant value shows that the construction of the Trans Java toll road in general reduces the IKLH. Meanwhile, the interaction coefficient of Central Java with a positive value although not statistically significant indicates that the decline in IKLH in Central Java is relatively small compared to other regions, possibly due to the character of IKLH as a composite index that is also influenced by environmental components other than air quality such as: water quality, seawater quality, land cover.

The significance of the regency/city variable passed after the inclusion of Central Java interaction indicates the heterogeneity of the impact of the Trans Java toll road construction between regions. Central Java, as the main node of the national toll network, bears a greater environmental burden due to traffic intensity and logistics activities, so that the negative effects on IKLH are clearer and statistically measurable. It also refers to the network theory by Freeman (1979).

The regression results of the regional topography interaction in model (5) show that districts/cities that have basins and valleys will get a significantly different impact of IKLH from areas that do not have basins and valleys, a significance level of 1%. This is due to the complex components that form IKLH so that the influence of environmental components other than air quality such as: water quality, seawater quality, land cover is still quite good in basin and valley areas and can reduce the impact of air quality.

Table 3. The Impact of the Operation of the Trans Java Toll Road on the Environmental Quality Index, base results

Variable	(1)	(2)	(3)	(4)	(5)
District/Town Passed	-0.230	-0.200	-0.458	-4.020***	-2.648
	(2.757)	(2.760)	(2.755)	(0.367)	(1.920)
Ln PDRB per capital		2.955	0.353	0.667	1.278
		(10.028)	(9.806)	(9.784)	(9.665)
Ln Density			-6.601	-6.522	-6.464
			(4.155)	(4.153)	(4.171)
Central Java Interaction				4.381	
				(3.161)	
Topographic Interaction					7.578***
					(0.882)

Variable	(1)	(2)	(3)	(4)	(5)
District/Town Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes	Yes
Observations	332	332	332	332	332
R^2 (within)	0.530	0.530	0.534	0.535	0.535

Impact on Carbon Emissions

In column 4, after the interaction of toll road effects in Central Java, the results show that after the operation of the Trans Java toll road increased carbon emissions by 0.812 percentage points, but statistically insignificant. This shows that there are different variations in districts/cities in Central Java, but not significant. In column 5, after the topographic interaction of the basin and valley areas, the results show that after the operation of the toll road increases carbon emissions by 0.598 percentage points, but it is not statistically significant. This shows that there is a variation in the impact on the quality of the environment when viewed in terms of regional topography.

In theory, the impact of toll road operation on carbon emissions can be positive and negative. The effect of increased emissions is caused by increased traffic so many cars pass by because of increased economic activity and mobilization (urban sprawl). On the contrary, the existence of toll roads will have the effect of reducing emissions caused by shorter travel time (fuel consumption per km decreases) and reduced congestion.

Table 4. The Impact of the Operation of the Trans Java Toll Road on Carbon Emissions, base results

Variabel	(1)	(2)	(3)	(4)	(5)
District/Town Passed	0.113	0.112	0.060	-0.632	-0.252
	(0.466)	(0.469)	(0.477)	(0.495)	(0.414)
Ln PDRB per capital		0.126	-0.730	-0.643	-0.697
		(3.193)	(3.124)	(3.135)	(3.065)
Ln Density			-2.008	-1.823	-1.673
			(2.577)	(2.591)	(2.554)
Central Java Interaction				0.812	
				(0.580)	
Topographic Interaction					0.598
					(0.722)
District/Town Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes	Yes
Observations	374	374	374	374	374
R^2 (within)	0.219	0.219	0.221	0.225	0.225

The estimated results show that the operation of the Trans Java toll road does not have a statistically significant impact on regency/city carbon emissions. These findings indicate that the effect of toll roads on emissions is likely to be small, heterogeneous, or internegotiable between increased transportation activity and travel efficiency.

If associated with empirical studies of previous studies, the results of the study show that the operation of the Trans Java toll road does not have a significant impact on KPIs, IKLH, or overall carbon emissions, in line with the findings of some literature that emphasizes that the environmental impact of toll road construction is contextual and not always universal. Several studies in Indonesia show that the construction of toll roads can cause environmental degradation, increased air pollution, and reduced productive land (Khasanah et al., 2017; Sumaryoto, 2010; Muyasaroh & Herlina, 2022). However, some international studies have given more mixed results, some stating that improving road infrastructure can improve air quality through reducing congestion and improving transportation efficiency (Sun et al., 2019; Ye & Li, 2024; Harleman, 2023), while several other studies show that road infrastructure actually increases air pollution and carbon emissions, especially in dense urban areas or industrial areas (Liu et al., 2021; Xie et al., 2017; Zhang et al., 2013).

The findings of the study show that the impact of toll roads on air quality and environmental quality are significantly negative in Central Java, making an important contribution to clarifying spatial variations. This variation is consistent with the literature evidence that the effects of road construction are strongly influenced by local economic structure, industrial intensity, heavy vehicle volume, regional morphology, and meteorological conditions (Kai Zhang & Batterman, 2013; Zhi Luo et al., 2018). The significant decline in air quality and the environment in Central Java in this study is in line with research that found that areas with high logistics activity, predominance of labor-intensive industries, and geographical conditions such as basins are more susceptible to air quality decline due to increased traffic and particulate emissions ($PM_{2.5}$ and PM_{10}).

Overall, the results of this study reinforce the view that the impact of toll road construction is not a homogeneous phenomenon, but is highly dependent on the regional structure, urbanization level, traffic intensity, and environmental conditions. This is in line with the recent literature on spatial effects (Ye & Li, 2024; Xu, 2023), which emphasizes the importance of considering regional condition variables in evaluating the impact of large infrastructure. Therefore, the findings of this study not only expand the empirical evidence in the Indonesian context, but also affirm the need for infrastructure policies that consider regional heterogeneity as well as the principles of sustainable development so that economic benefits can be achieved without sacrificing environmental quality.

The findings regarding the presence of spatial variation confirm the theory *Network1* namely the centrality of the network, negative externality to the IKU in Central Java can be understood as a structural consequence of its role as a transit area with Degree, betweenness, and closeness centrality which is high in the Trans Java toll road route network. This suggests that the connectivity and efficiency benefits of national transportation are not distributed, but rather accompanied by a greater environmental burden on the main transit node areas. Therefore, these findings underscore the importance of spatial-oriented environmental mitigation policies, such as controlling heavy vehicle emissions, developing green corridors, and integrating low-emission transportation, especially in areas with high network centrality such as Central Java.

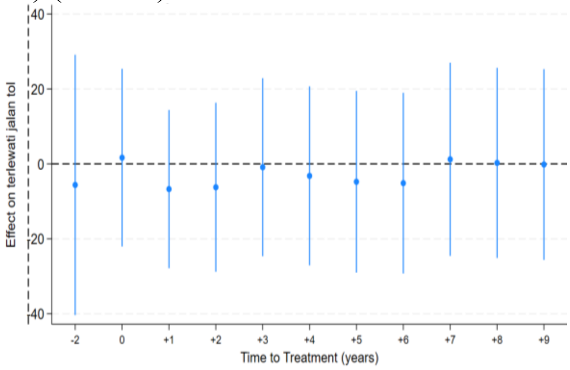
The study also confirms that the topography of the area in the form of basins and valleys has an influence on the overall quality of the environment, and significantly affects IKLH where areas that have basin and valley topography tend to get lower than other regions.

Dynamic Analysis

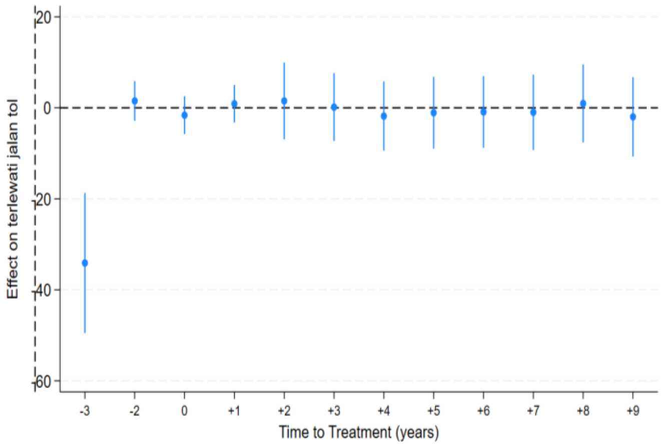
The results of the dynamic study generally confirm that the environmental impact after the operation of the Trans Java toll road is dynamic, temporary, and heterogeneous between indicators, and does not show a pattern of persistent environmental degradation in the long term. These findings emphasize the importance of paying attention to the time dimension in evaluating the environmental impact of infrastructure development.

IKU decreased after treatment up to the 6th year of treatment and changed in the 7th year to relatively increase. These results show that in the short term, the operation of toll roads will have an impact on reducing KPIs, however, after the medium term (7 years after passing toll roads), the districts/cities that are passed will have a positive impact on increasing KPIs even though with insignificant values.

This confirms that the findings of road infrastructure can provide environmental health benefits (reducing air pollution), although it must consider the temporary adverse impacts during the construction period. Harleman (2023) said that infrastructure development in developed countries increases vehicle congestion during construction and reduces congestion three years after construction is completed. The tendency of the long-term positive impact on the KPI is suspected to be caused by several factors, including travel efficiency on toll roads resulting in reduced travel time, traffic redistribution, and vehicle modernization (such as electric and hybrid vehicles) (Chart 1).

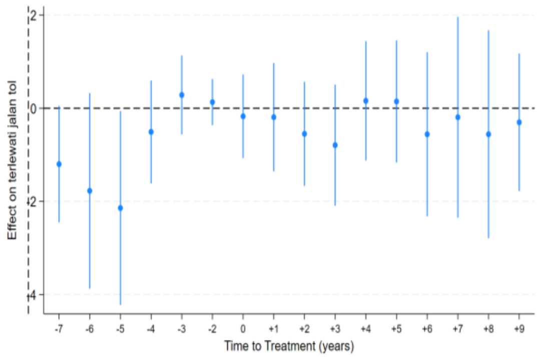


Graph 1. Dynamic Analysis of the Impact of Toll Roads on IKU



Graph 2. Dynamic Analysis of the Impact of Toll Roads on IKLH

Graph 2. shows the consistent impact of IKLH movements from the period before to after the toll road is operational, showing that toll road construction seems to have a neutral impact on IKLH in general. The presence of treatment did not have a statistically significant effect on IKLH or outcome in any year observed, either before, during, or after the operation of the toll road, compared to the control group. The neutral impact is suspected to be caused because IKLH is a composite index of several components where the negative impact of toll road construction to one of the components that form the index, sets off each other with the positive impact caused.



Graph 3. Dynamic Analysis of the Impact of Toll Roads on Carbon Emissions

Overall, there is no strong evidence that treatment and control groups have consistently different trends before policy. This shows that before the operation of toll roads, carbon emissions in districts/cities that were passed and not passed moved relatively in line or did not differ significantly. In the period after the operation of the toll road, the short-term impact has the potential to reduce carbon emissions and for the medium term the impact is insignificant (weak). The relatively stable of carbon emissions despite the increase in the amount of traffic is assumed by several factors such as smoother movement of traffic flows with the existence of toll roads, travel efficiency, and increasingly modern vehicle technology (Graph 3).

Externality to Environmental Aspects

Clean air is public good which is not exclusive (non-excludable) and *non-rival*. Environmental externalities, such as air pollution, increased carbon emissions, and decreased environmental quality, are an inseparable consequence of people's economic activities. Given the large impact of these externalities on health, environmental sustainability, and the sustainability of economic development, policy interventions are needed to control them. Countermeasures can be carried out through public policies, including the implementation of economic instruments such as the Pigovian tax through the carbon tax policy.

CONCLUSION

This research provides empirical evidence showing that, at the national aggregate level, the Trans Java Toll Road has no statistically significant impact on environmental quality metrics such as KPIs, IKLH, and carbon emissions in affected districts/cities. However, spatial heterogeneity reveals significant variations: regencies/cities in Central Java Province experienced notable declines in KPIs and IKLH, driven by high network centrality (degree, betweenness, and closeness) as key transit nodes bearing greater environmental burdens from traffic and logistics, compounded by basin/valley topographies that hinder pollutant dispersion. These findings align with literature on local economic structures, industrial intensity, vehicle volumes, morphology, and meteorology. Overall, the study confirms spatially heterogeneous environmental impacts influenced by transportation network position and regional physical conditions, implying the need for targeted, spatial-oriented mitigation strategies in high-vulnerability areas like Central Java to balance economic benefits with environmental quality. For future research, integrating real-time air quality monitoring data with machine learning models could enhance predictive accuracy of spatial impacts and evaluate long-term policy effectiveness.

REFERENCES

Angrist, J. D., & Pischke, J.-S. (2009). Mostly Harmless Econometrics: An Empiricist's Companion. Princeton University Press.

April, et al. al., (2025). Toll Road Infrastructure Development Policy Evaluation of the Impact of Toll Road Development on Improving Inter-Regional Connectivity, Regional Economic Growth, and Its Impact on Society and the Environment. Scientific Journal of Economics 1(2), Year 2025. 44-53

Berawi, M. A., Zagloel, T. Y., Miraj, P., Berawi, A. R. B., Titaheluw, W., & Karim, S. B. B. A. (2016). Developing road infrastructure route planning: Increasing feasibility of toll road project. *Makara Journal of Technology*, *20*(3), 7.

Dewi, O. P. T., Warlina, L., & Sodikin. (2025). Environmental impact analysis of the infrastructure development of the Jakarta-Cikampek II Selatan Toll Road. Domain Research Journal of Multidisciplinary Research and Development, 7(4), 2426–2437. https://doi.org/10.38035/rrj.v7i4.2426-2437

Forman, R. T. T., & Alexander, L. E. (1998). Roads and their major ecological effects. Annual Review of Ecology and Systematics, 29, 207–231.

Freeman, L. C. (1979). Centrality in social networks: Conceptual clarification. Social Networks, 1(3), 215–239. https://doi.org/10.1016/0378-8733(78)90021-7

Hafnidar, A., & Azlan, M. (2020). The impact of the construction of the Banda Aceh-Sigli Toll Road on the environment. Journal of Civil Engineering, University of Muhammadiyah Aceh, 9(1), 11–21.

Harleman, M. (2023). Changes in traffic congestion and air pollution due to major roadway infrastructure improvements in Texas. Science of the Total Environment, 898, 165462. https://doi.org/10.1016/j.scitotenv.2023.165463

Kai, Z., & Batterman, S. (2013). Air pollution and health risks due to vehicle traffic. Science of the Total Environment, 307–316. https://doi.org/10.1016/j.scitotenv.2013.01.074

Lee, W.-S., et al. (2023). Green infrastructure and air pollution: Evidence from highways connecting two megacities in China. Journal of Environmental Economics and Management, 122, 102884. https://doi.org/10.1016/j.jeem.2023.102884

Luo, Z., et al. (2018). Urban pollution and road infrastructure: A case study of China. China Economic Review, 49, 171–183. https://doi.org/10.1016/j.chieco.2017.04.008

Masrida, R. (2024). Evaluation of environmental quality as a result of the operation of the Solo-Mantingan Toll Road in the Colomadu-Karanganyar segment. Journal of Industrial and Engineering Systems, 4(2), 117–127.

Muyasaroh, & Herlina. (2022). Toll road development and environmental change: A Maqashidi study at Indralaya–Muara Enim. Millah: Journal of Religious Studies, 21(3), 821–862. https://doi.org/10.20885/millah.vol21.iss3.art8

Government of the Republic of Indonesia. (2005). Government Regulation Number 15 of 2005 concerning Toll Roads.

Government of the Republic of Indonesia. (2024). Government Regulation Number 23 of 2024 concerning the Implementation of the ASN Law. State Secretariat.

Pindyck, R. S., & Rubinfeld, D. L. (2018). Microeconomics (9th ed.). Pearson Education.

Rodrigue, J.-P., et al. (2020). The geography of transport systems (5th ed.). Routledge.

Sharif, F., & Tauqir, A. (2021). The effects of infrastructure development and carbon emissions on economic growth. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-021-12936-4

Sun et al., (2019). Urban Public Transport and air quality: Empirical Study of China Cities. Journal of Energy Policy, 135, 1–9.

Situmorang, H., Nuraini, C., & Sugiarto, A. (2025). The Effect of Trans Sumatra Toll Road Infrastructure Development on Regional Development in Asahan Regency. *East Asian Journal of Multidisciplinary Research*, *4*(2), 901–914.

World Bank. (1994). World development report: Infrastructure for development. Oxford University Press.

World Bank. (2020). Sustainable infrastructure framework for decision making. World Bank Group.

Xie, R., Fang, J., & Liu, C. (2017). The effects of transportation infrastructure on urban carbon emissions in China. Energy Policy, 109, 1–12. https://doi.org/10.1016/j.enpol.2017.06.060

Ye, F., & Li, Y. (2024). Road traffic infrastructure construction and air pollution: Spatial spillover perspective. Sustainability, 16, 9627. https://doi.org/10.3390/su16229627

Zhang, M., et al. (2021). Assessing the influence of urban transportation infrastructure construction on haze pollution in China. Environmental Impact Assessment Review, 87, 106547. https://doi.org/10.1016/j.eiar.2020.106547