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Reduction of Greenhouse Gas Emissions through Infrastructure Export: Verification Using Modal Shift

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Abstract: This study estimated that railway projects funded by Japanese ODA loans contributed to CO_2 reductions through 14 rail projects in five countries (India, Indonesia, Thailand, China, and the Philippines). The GHG (greenhouse gases) reduction effect in Japanese ODA projects that were implemented in five countries was about 6 million tonnes of CO_2. On the other hand, not all projects have contributed to reducing GHG. For example, when GHG emissions from the power generation sector were large, it was suggested that a modal shift to trains would increase GHG emissions from the power generation sector, and that GHGs could be higher than BAU (business as usual) scenario.

Keywords: Infrastructure export, railway, greenhouse gases reduction, Japanese ODA, Clean Development Mechanism

JEL Classification Numbers: Q54, Q56, Q57

1. Introduction

Infrastructure export is cited as a Japanese growth strategy. With rapid urbanisation and economic growth particularly in developing countries, business strategies that focus on the overseas market are increasingly important. Japan aims to increase infrastructure exports to 30 trillion yen (about 300 billion US$) by 2020.

Infrastructure exports are also expected to contribute to solving global environmental problems and to disaster prevention, as well as in helping improve lifestyles in a partner country. One of the contributions in the environmental field is the reduction in greenhouse gases (GHGs). The electricity-generating sector is the largest emitter of greenhouse gases, followed by the transport sector. Electric power and transportation demanded by developing countries, which increase with expensive technological infrastructure, cannot contribute to the mitigation of global warming.

To mitigate climate change, it is necessary for all countries to be involved. Currently, China is the world's largest emitter of CO_2, and without the cooperation of China and other developed countries, it will be impossible to solve the problem of climate change as the amount of GHG emissions from these countries.

This study estimates the reduction effects of GHG emissions through 14 rail projects (subway, monorail, and diesel train) in five countries (India, Indonesia, Thailand, China, and the Philippines). All the projects were funded by yen loans (ODA: Official Development Assistance) and were selected because detailed information was available regarding both the establishment and operation of these projects. In this study, I evaluate the reduction effect of the railway project, but consider not only the GHG emissions from the transportation sector but also the emissions from the energy sector for moving electric trains and diesel trains. In the previous study that estimated the reduction effect of the railway sector estimated the GHG reduction effect due to saving of fuel such as buses and cars, and there are many studies only in a specific country or transportation sector(He & Xu(2011), Song, et al.(2019), Kumar, et al. (2018), Tsumura, et al.(2019)). This study evaluates projects implemented in multiple countries. As a result, it is possible to see the effects of railway projects in countries with different energy and traffic structures.

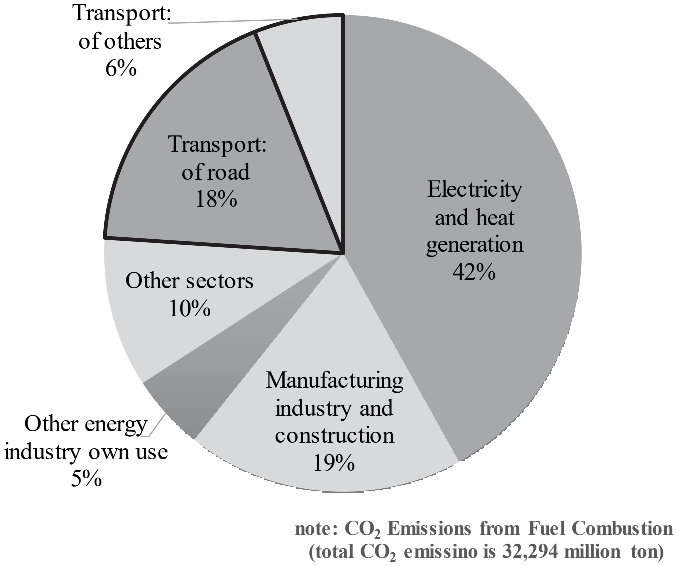
2. Energy and GHG emissions in the transportation sector

The transportation sector (transportation sector means sum of the "transport: road" and "transport: others") is the second-largest emitter of GHGs, accounting for 24% of all emissions (see Figure 1), and this amount is increasing each year. GHG emissions from transportation more than doubled between 1971 and 2008 (IEA, 2017a).

The GHG emissions from the transportation sector increase with the rise in income level. Figure 2 shows the population size and GHG emissions from the transportation sector in Organisation for Economic Co-operation and Development (OECD) and non-OECD countries. The population size of non-OECD countries is five times that of OECD countries, but the CO_2 emissions from the transportation sector are only 60% of those of OECD countries. Per capita annual CO_2 emissions from the transportation sector are 2.8 t-CO_2 in OECD and 0.4 t-CO_2 in non-OECD countries. If the amount of per capita emissions of the transportation sector in non-OECD countries reaches the same level as that of OECD countries, then the total global amount of GHGs emissions will increase by around 40%.

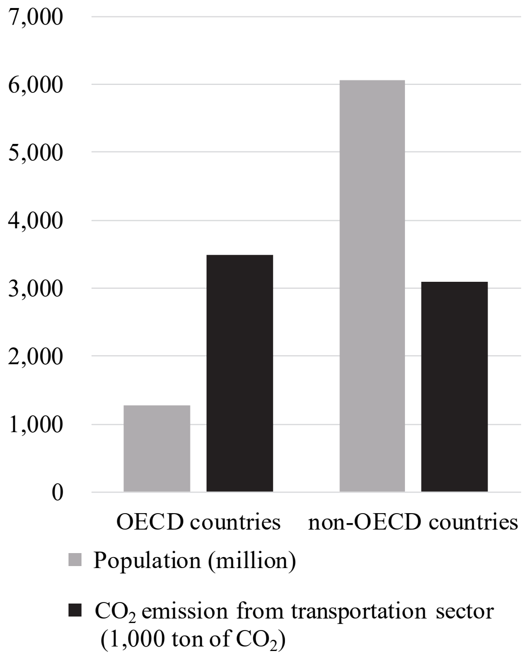
What, therefore, is the GHG emissions structure in the transportation sector? Figure 1 also shows that travel by road produces the largest emissions. Because transportation needs increase with an increase in income, the mitigation of emissions from the transportation and road traffic sector is one of the most important problems that needs to be addressed. Emissions can be calculated as Emission = Carbon content (CO_2/MJ) × Energy intensity (MJ/pkm) × Transportation demand (pkm). When reducing the amount of emissions from road traffic, it is necessary to reduce the amount of emissions from each factor. Thus, reducing carbon content means switching to fuels with low carbon content, for example, converting from fossil fuel to biofuel (Haroon, 2000). Improving engine efficiency, making a modal shift from light-duty vehicles (LDVs) to a mass transportation system, and increasing the load factor are effective measures to lower energy intensity. In addition, improving roads, such as shorting and flattening roads, can reduce the amount of emission from transport sector (Source: IEA, 2009; OECD/ITF, 2000; David, 2007; Cefic and ECTA).

Figure 1. Global CO_2 emissions by sector in 2015



Source: IEA (2017a)

Figure 2. Amount of CO_2 emissions from the transportation sector (2015)



Source: IEA (2017b), IEA (2018)

The International Energy Agency (IEA) anticipates that the four most important modes that will contribute to CO_2 emissions in the baseline scenario in 2050 are LDVs at 43%, trucks at 21%, aviation at 30%, and shipping at 8%. Additionally, it predicts that buses and rail lines will increase significantly and that CO_2 reduction via efficiency and the use of alternative fuels will become increasingly important in these modes.

This study examines how a modal shift from road to mass transportation through railroads affects GHG emissions. The main objectives of railway projects conducted through the Japanese ODA are to enhance regional economic development or to reduce air pollution by constructing subways or railways, and not to reduce the amount of GHG emissions. Therefore, the GHG reduction effect because of the modal shift is estimated as a co-benefit effect.

3. Research subject and methodology

3.1. Projects

This study aims to estimate the GHG emissions reduction through railway projects. The effect is calculated as the gap between the emission levels at the baseline and those achieved owing to railways constructed through the selected projects. This study estimates the reduction effects of 14 railway projects in five countries: India, Indonesia, Thailand, China, and the Philippines, as indicated in Table 1. The main objective of these projects is to promote regional economic development and improve the urban environment through the alleviation of traffic congestion and the reduction of pollution caused by motor vehicles. There are other forms of financing than yen loans that contribute to the construction of a railway. In this study assumes that the net contribution of the yen loan for CO_2 reduction can be calculated by multiplying the estimated total amount of CO_2 by the ratio of the amount of the yen loan and the whole project cost.[1] For the detail information of the project, refer to the appendix 1.

3.2. Methodology of GHGs reduction effect

The GHG emissions reduction effect is calculated as the emission gap between the baseline and the transportation projects. The amount of the reduction effect refers to the appraisal technique of the Clean Development Mechanism (CDM), which is approved by the United Nations. The GHGs reduction effect in the transportation sector refers to the ACM0016: 'Mass Rapid Transit Projects' and AM0090: 'Modal shift in transportation of cargo from road transportation to water or rail transportation', or JICA Climate-FIT (Mitigation) (JICA Climate Finance Impact Tool/Mitigation) Draft Ver. 1.0, June 2011). However, because detailed data and monitoring information for every project are necessary to apply the CDM evaluation methodology, it is difficult to estimate the reduction effect of all projects using such methodology. For simplification, while referring to the CDM methodology, the reduction effect is estimated using the following procedures.

Table 1. Project Summary

No.	Country	Project type	Scale(km)	Scale(Mpkm)	Scale(Mtkm)
1	China	Electric, P, New	4	322	---
2	China	Electric, F, New	154	---	9,216
3	China	Electric, P, New	8	151	---
4	China	Electric, P and F, New	42	194	739
5	China	Electric, P and F, Double	57	50	450
6	China	Electric, P and F, New	139	252	1,559
7	China	Electric, F, New	88	---	6,267
8	China	Diesel, F, New	40	---	246
9	China	Diesel, F, New	191	247	12,581
10	India	Electric, P, New	35	2,494	---
11	Indonesia	Diesel, P and F, Double	59	244	23
12	Indonesia	Diesel, P and F, Double	51	367	-24
13	Philippines	Electric, P, New	8	247	---
14	Thailand	Electric, P, Double	10	315	---
		Train total	886	4,882	31,057

note)P=Passsenger, F=Freight, New=New coustruction, Double=Double-truck, Mpkm=Million passenger-km, Mtkm=Million ton-km

Source: created by author from JICA Website of ODA Loan Project DATA

The project intends to reduce GHG emissions by realising a 'modal shift' from existing passenger transport systems, that is, conventional buses, passenger cars, taxis, and bicycles, to passenger railway systems, such as a new, double-track, or quadruple-track railways. In addition, the 'electrification' of passenger railway systems will reduce GHG emissions.

The GHG emissions reduction amount is calculated as the difference between the project emission (*PE*) and the baseline emission (*BE*) amounts:

$$ER_{i,y} = BE_{i,y} - PE_{i,y}, \qquad (1)$$

where $ER_{i,y}$ is GHG emissions reduction due to i project activity in year y (t-CO_2/y), $BE_{i,y}$ is baseline emissions (GHG emissions with existing transport systems in year y (t-CO_2/y)), and $PE_{i,y}$ is project emissions (GHG emissions following a successful modal shift to the passenger/freight railway from the existing transport systems in year y (t-CO_2/y)).

According to the CDM methodology, project emissions is the sum of the 1) emissions based on the fuel and/or electricity consumed by the project railway (direct project emission) plus 2) emissions caused by project passengers from their trip origin to the entry station of the project, and from the exit station of the project to their destination (indirect project emissions). However, as we cannot collect the indirect project emissions using the available data, project emissions mean only direct project emissions in this study.

In contrast, baseline emissions (for passenger transportation) are defined as

$$BE_{i.y} = \frac{P_{i,y}}{P_{SPER}} \sum_p \left(BE_{p,i,y} \times FEX_{p,i,y} \right), \quad (2)$$

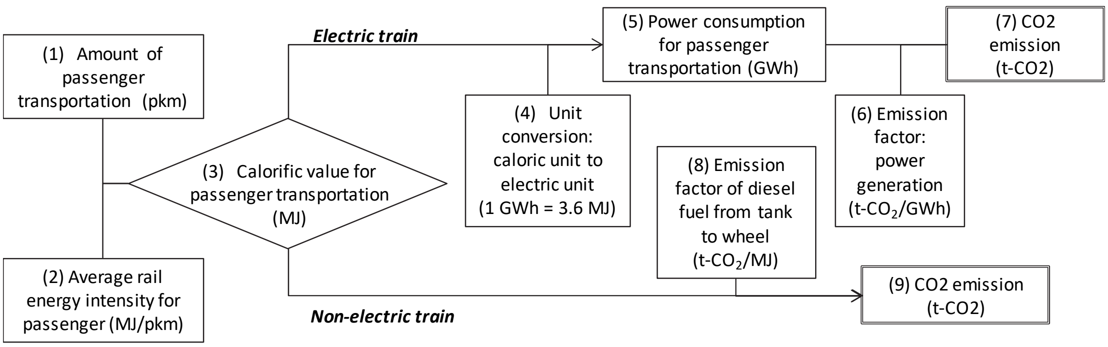
where BE_y is baseline emissions in year y (t-CO_2), $BE_{p,y}$ is baseline emissions per surveyed passenger p surveyed in year y (each surveyed passenger has a different expansion factor), P_y is the total number of passengers in year y, P_{SPER} is the number of passengers in the time period of the survey (1 week), p is the surveyed passenger (each individual), y is the year of the crediting period, and i is each project.

Surveys are required to estimate the baseline and project emissions, but these surveys were not conducted. Hence, for example, we created the basic unit to collect macro-level data using the following estimation methods:

1) Estimation process and data of the reduction effect (Case of passenger travel)

Here, I explain how to estimate GHGs reduction effects from passenger travel project. The freight projects are based on an estimation process for passenger. GHG emissions include fuel emission. In other words, when using gasoline or diesel, the GHG emissions from the process of using the fuel are measured. When using electricity like a train, the amount of GHG emitted to generate electricity is measured. From formula (1), the GHGs reduction effect by a passenger transport railway project is calculated by detecting the amount of project emissions from the amount of the baseline emissions. Figures 3 and 4 show the estimation flow of the baseline and project emissions.

Figure 3. Estimation flow of the project emissions (Passenger transportation)



Data source
(1) JICA website
(2) IEA/SPM (2004)
(6) IEA(2011a, 2011b, 2011c)
(8) IPCC (1996)

The estimation process and the data change with an electric train or a non-electric train (diesel) are indicated in Figure 3. Moreover, the estimation process changes with urban or long-distance railways shows in Figure4. The data used for estimation are displayed below.

Figure 4. Estimation flow of the baseline emissions (Passenger transportation)

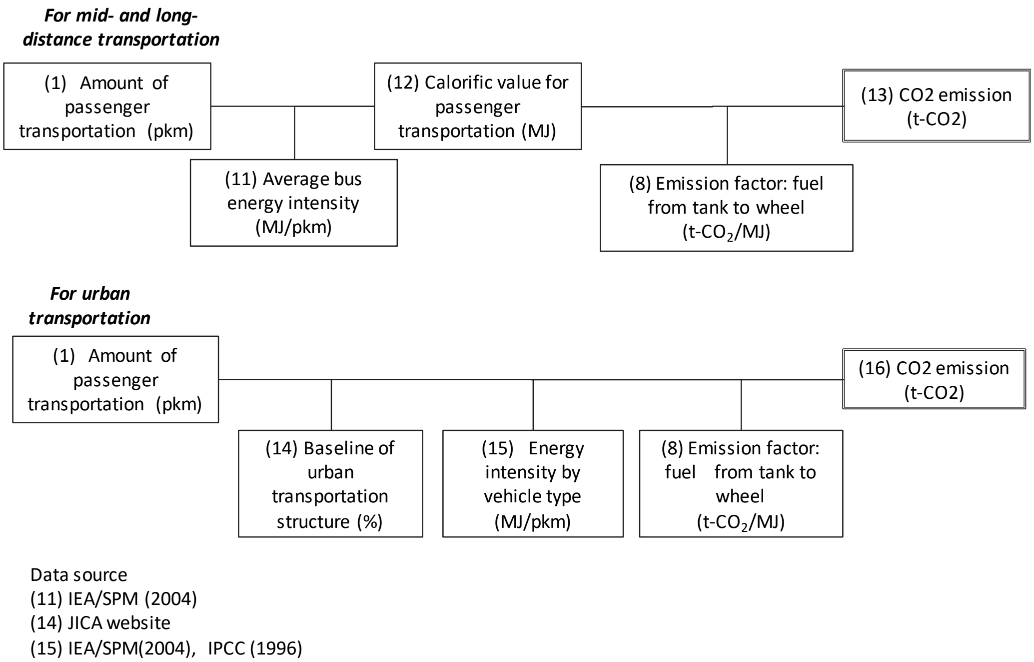


Table 2 presents the energy intensity (passenger and freight) of railways in 2000, and the average annual rate of energy improvement. It was assumed that the annual energy intensity changed with improvement rates.

Table 2. Rail Energy Intensity

	Average rail energy intensity, 2000		Average annual rate of improvement	
	Passenger	Freight	Passenger	Freight
	(MJ/pkm)	(MJ/ton-km)	(%)	(%)
FSU	0.3	0.2	1.0%	2.0%
China	0.3	0.2	1.0%	3.0%
Rest of Asia	0.3	0.2	1.0%	3.0%
India	0.3	0.2	1.0%	3.0%
Africa	0.3	0.2	1.0%	3.0%
OECD Pacific	0.3	0.4	1.0%	2.0%

Source: Fulton and Eads (2004)

For example, (3) calorific value for passenger transportation (MJ) can calculate (1) amount of passenger transportation multiplied by (2) rail energy intensity. For rail transportation, the energy consumption varies significantly according to the type of train, of which there are two basic types, electric and non-electric (diesel). The estimation method is divided according to railroad type.

In the case of the electric train, (3) calorific value changes to (5) power consumption for passenger transportation (GWh) through (4) unit conversion. Estimation of (7) CO_2 emissions (t-CO_2) are multiplied by (6) the emission factor, power generation (t-CO_2/MJ). Because (6) the emission factor of the power generation sector is significantly different in terms of the energy use structures and the technical levels of a country, we used the emission factor of each individual country (Table 3).

Table 3. Emission Factor of Power Generation (t-CO_2/GWh)

	China	India	Indonesia	Philippines	Thailand
2005	1.004	0.784	0.728	0.499	0.541
2006	0.990	0.771	0.748	0.437	0.516
2007	0.939	0.797	0.780	0.450	0.552
2008	0.885	0.806	0.759	0.492	0.535
2009	0.869	0.830	0.757	0.483	0.519
2010	0.860	0.806	0.722	0.489	0.518
2011	0.862	0.777	0.762	0.500	0.528
2012	0.832	0.820	0.719	0.510	0.506
2013	0.807	0.782	0.665	0.577	0.530
2014	0.775	0.808	0.741	0.604	0.536
2015	0.750	0.777	0.733	0.614	0.512

Source: Estimation from IEA (2017a)

The emission factor of power generation is large in a country in which fossil fuel use is high, and the energy efficiency of power generation is low.

In contrast, the (9) CO_2 emissions from non-electric railway projects (t-CO_2) can be calculated by multiplying the (3) calorific value for passenger transportation (MJ) and (8) the emission factor of fuel (t-CO_2/MJ). The value of (8) the emission factor of fuel uses the Intergovernmental Panel on Climate Change (IPCC; Table 4). Hence, we assume that a non-electric train uses diesel as fuel.

Table 4. CO_2 Emission Factor from Fuel

	Net calorific values	Emission factor	
	(MJ / litter)	(g-CO_2 / MJ)	(g-CO2 / litter)
Gasoline	44.8	69.3	3,105
Diesel oil	43.3	74.1	3,209

Source: IPCC (1996)

The amount of baseline emissions when a project is not undertaken was estimated along with the flow, as shown in Figure 4. Here, the estimation flow differs according to long- and mid-distance transportation, and urban transportation. Long- and mid-distance transportation assumes that a bus is used as baseline transportation.

The amount of baseline emissions in the case of urban transport is estimated differently, using the following procedures. Initially, when an urban transportation project is not undertaken, it is assumed that the alternative urban transportation will be dependent on the transportation structure that existed prior to implementation of the project. The amount of (16) CO_2 baseline emission (t-CO_2) is estimated by multiplying the energy intensity of those alternative transportation forms, and emission factors (t-CO_2/MJ) of the fuel to be used.

Urban transport projects are the following six projects: Project number 1, 3, 10, 13, and 14. The urban transport structure prior to a project is summarized below. When the urban transportation project is not undertaken, it is assumed that a passenger uses the vehicle of the "baseline setup" (Table 5).

Table 5. Baseline Urban Transportation Structure

No.	Country	City	Baseline transportation structure (Source: JICA website)	Baseline setup
1	China	Beijing	Bus 8,7225 million people, taxi 638 million people, subway 463 million people (Passenger transport performance, 1998)	Assuming 85% and 15% bus and taxi traffic
3	China	Chongqing	Bus 3.3 million people, small bus 930 thousand people, taxi 200 thousand people, private car 100 thousand people, others 240 thousand people (travel passenger per day in 2005)	Assuming 95% and 5% bus and taxi traffic
10	India	Delhi	Motorcycle 2.2 million unit, automobile 841 thousand unit, other vehicle 138 thousand unit (registration base in 2000)	Assuming the proportion of motorcycles and automobiles to be 50/50
13	Philippines	Metro Manila	No data	Assuming 100% bus
14	Thailand	Bangkok	Bus 51%, Automobile (automobile, taxi, van) 30.8%, motorcycle 12.7% (Transportation used before the start of the project: Questionnaire-based)	Assuming 58%, 35% and 6% of bus, car and motorcycle

4. Results

The results of GHG emissions reduction effect by train project through ODA shows in Table 6. The amount of the annual reduction effect was about 6.0 Mt-CO_2 in 14 projects in total, and this is equivalent to 0.5% of the total CO_2 emissions from Japan in 2015. Although the reduction effect of China is large, the results by passenger and freight differ greatly (Table 6).

Table 6. Results of GHG emissions reduction effect by train projects (unit: 1,000 t-CO_2/year)

No.	Country	For passenger	For freight
1	China	-5.0	---
2	China	---	1851.5
3	China	-4.3	---
4	China	-6.8	148.5
5	China	-2.0	86.5
6	China	-8.8	313.3
7	China	---	1258.9
8	China	---	55.8
9	China	---	2527.4
10	India	36.2	---
11	Indonesia	3.1	4.2
12	Indonesia	0.3	
13	Philippines	-1.2	---
14	Thailand	12.5	---

The reduction effect by freight transportation is largest, and passenger transport has many projects in which the reduction effect is negative. The negative sign means that the amount of GHG emissions increased as a result of the modal shift by a project.

The GHGs discharged by the vehicles (a bus, car, taxi, two-wheeled vehicle, etc.) of the traffic structure that exists before a project is conducted is smaller than those discharged from a railroad that is constructed by a project. That is, the GHG emissions from a railway that is built by a project are larger than that of the vehicles (bus, car, taxi, or two-wheeled vehicle) of the traffic structure that exists prior to a project being conducted.

The project taken up in this study is just a part of the traffic volumes of each country. For example, annual amount of passenger travel in China is about 8 trillion pkm in 20000, and the volume of freight travel is about 4 trillion tkm. The Chinese 14 projects taken up this time occupy less than 0.1 % of passenger movement and about 0.8% of freight transportation in whole China. And urban transportation structure differs by country or region. The GHG reduction effect to the Chinese passenger transportation was minus in this study, but it's possible to reduce GHGs by a railroad in India and Indonesia. In this study did not clarify the effect of reducing the passenger transportation sector, the reduction effect is different depending on the original structure of urban transportation. But the big effect can be expected relatively about a modal shift to a railway from a track of long-distance freight transportation.

5. Considerations

This study estimated that railway projects funded by yen loans substantially contributed to CO_2 reductions. The GHG reduction effect in Japanese ODA projects that were implemented in five countries was about 6 million tonnes of CO_2, which is equivalent to 0.5% of Japan's total emissions in 2015. The reduction effect is large in long- and mid-distance freight railways.

In contrast, the reduction effect of some passenger transportations by electric railway is negative. Because many GHGs were discharged through the electricity generation process, which is the driving force of the electric train, the effect of GHG reduction was shown to be negative. While the emission factor of the power generation sector of China, which is the same as that of Japan, was negative, other projects displayed an improvement (a reduction contribution is estimated).

The modal shift from road traffic, which uses gasoline and diesel as fuel, to trains is also anticipated in the field of energy conservation. However, if the amount of emissions from power generation sectors is not considered, the overall amount of emissions will increase. To evaluate the GHG reduction effect of a railway project, comprehensive evaluation is required not only of the transportation sector but also of the energy efficiency and emission structure of the power generation sector. Moreover, assumptions about the baseline also significantly influence the results. Although the reduction effect of a railway for a freight transport project is large, one of the reasons for this is the assumption that trucks are used when a project is not conducted. Also, the reduction effect may differ depending on the development stage when the urban transport project was implemented. The background of the project implementation depends on the situation of the country and the city, so it is a future task to improve the accuracy of the estimation method and to consider the impact of the development stage.

In this study, because monitoring data could not be used, estimations were made using macro data. Because a database was not constructed, the detailed energy data of a developing country are especially difficult to obtain. However, the original unit in this study was created and estimated based on the data of the area and the country using it, the estimation result changes significantly according to the original units. Therefore, verification of the basic unit is a subject for future research. Furthermore, because data related to indirect emissions or leakage was not used in this study, I would like to focus on these issues as subjects for future research.

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Appendix1: Detail information of object projects

No.	Country	Project name	Main purpose	Project summary			Total cost	ODA	Share of ODA	Adjusted by ODA loan ratio: Line distance	Adjusted by ODA loan ratio: Passenger transportation volume	Adjusted by ODA loan ratio: Freight transportation volume
							bn. yen	bn. yen	%	km	mil. pkm / y	mil. tkm / y
1	China	Beijing Urban Railway Construction Project	Reducing urban traffic congestion and improving air pollution	New	E	Urban transportation (subway, ground line, elevated line)	89.3	8.1	9%	3.7	321.9	
2	China	Shuoxian - Huanghua Railway Construction Project	Regional economic development by strengthening coal supply capacity	New	E	Long distance (for coal)	235.4	60.3	26%	153.5		9,216.4
3	China	Chongqing Urban Railway Construction Project)	Reducing urban traffic congestion and improving air pollution	New	E	Urban transportation (monorail)	46.0	27.1	59%	7.9	151.2	
4	China	Xi'an-Ankang Railway Construction Project	Regional economic development by strengthening transportation capacity	New	E	Long distance	158.9	27.0	17%	42.0	194.4	739.1
5	China	Guiyang-Loudi Railway Construction Project	Regional economic development by strengthening transportation capacity	Double track	E	Long distance	221.0	15.7	7%	57.3 *	49.7 *	449.9 *
6	China	Baoji - Zhongwei Railway Construction Project	Regional economic development by strengthening transportation capacity	New	E	Long distance	107.0	29.8	28%	139.4	252.1	1,559.3
7	China	Shenmu-Shozian Railway Construction Project	Regional economic development by enhancing the coal transportation capacity	New	E	Long distance (for coal)	76.9	25.3	33%	88.2		6,266.6
8	China	Fujian Zhangzhou Railway Construction Project	Regional economic development by strengthening transportation capacity	New	D	Long distance	24.1	6.7	28%	39.7	NA	246.2
9	China	Hengshui-Shangqiu Railway Construction Project	Regional economic development by enhancing the coal transportation capacity	New	D	Long distance (for coal)	124.4	22.2	18%	191.3		12,580.6
10	India	Delhi Mass Rapid Transport System Project	Promoting regional economic development and improving urban environment	New	E	Urban transportation (subway, ground line, elevated line)	272.5	162.6	60%	35.1	2,494.3	
11	Indonesia	Railway Double Tracking on Java South Line Project	Contribute to the economic development by expanding line capacity	Double track	D	Long distance	16.4	15.1	92%	58.7 *	243.7 *	22.6 *
12	Indonesia	Rehabilitation of Bridges for Java North Line	Contribute to the economic development by expanding line capacity	Double track	D	Long distance	7.6	7.2	95%	51.1 *	366.5 *	-24.1 *
13	Philippines	Metro Manila Strategic Mass Rail Transit Development Project	Mitigation of urban traffic congestion and improvement of urban environment	New	E	Urban transportation (elevated line)	87.9	60.2	68%	8.4	246.6	
14	Thailand	Bangkok Subway Construction Project	Reducing urban traffic congestion and improving air pollution	New	E	Urban transportation (subway)	358.9	186.7	52%	10.5	315.3	

*Additional transportation due to double track, track repair, etc.

NA: Not Available, E:Electrification, D: Diesel