IMPACT OF A NEW RAILWAY STATION ON ENVIRONMENTAL ECONOMY FROM THE PERSPECTIVE OF GREENHOUSE GAS EMISSION

Yu-Cheng Lee¹, Yun-Chung Lee², Shu-Hua Rao²,³

¹Department of Technology Management, Chung-Hua University, 707, Sec. 2, WuFu Rd., HsinChu 300, Taiwan R.O.C.; E-mail: drlee168@gmail.com

²Ph.D. Program of Technology Management, Chung Hua University, 707, Sec. 2, WuFu Rd., Hsinchu 300, Taiwan R.O.C.;

³Department of Business and Entrepreneurial Management, Kainan University, No. 1, Kainan Road, Luchu, Taoyuan County, Taiwan R.O.C.; E-mail:jessier2355@gmail.com

*Corresponding author; Yun-Chung Lee
Ph.D. Program of Technology Management, Chung Hua University, No.707, Sec.2, WuFu Rd., Hsinchu 300, Taiwan. Tel: +886-903119136; E-mail:chris_lee@thsr.com.tw

ABSTRACT
Global warming is not only a crucial consideration for environmental economy, but is also currently of considerable importance worldwide. The reduction of greenhouse gas (GHG) emissions from the transportation system is a key global warming indicator. This study utilized the concept of emission mode shift to set up a GHG estimation method and calculate GHG emissions from the three new stations of the Taiwan High Speed Rail (HSR) Project.

The results revealed that the amount of GHG emissions avoided by the rail transit system (credit) was higher than that generated by the new stations and traction electricity demand (debit). Furthermore, the carbon reduction benefits of intercity public transportation by the road system were limited in comparison with those of the rail transit system.

KEYWORDS: rail transit system, greenhouse gas emission, high speed rail, mode shift, global warming
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1. INTRODUCTION

Environmental economy focuses on the loss of environmental pollution caused by human activities, including direct material loss, damage to human health, and indirect mental damage to humans. These losses can be assessed if the benefits of inputs to environmental improvements, such as direct pollution mitigation and indirect social and ecological benefits. Furthermore, an environmental accounting system can be established on the basis of the amount and damage of the pollutants and their mitigation cost (Giddings et al, 2002). Global warming is not only a crucial consideration for environmental economy but also is of considerable importance worldwide.

The reduction of greenhouse gas (GHG) emissions from the transportation system is a key global warming indicator. Those emissions from transportation systems account for approximately 23% of overall global emissions, and most of them are a result of the road system. Most countries have partially replaced road systems with a rail transit system to reduce GHG emissions in recent years. The energy of the rail transit system usually comes from the electric power. For instance, a London underground train consumes more than 1 billion KWh each year, which is London’s largest electric consumption unit and is almost 2.8% of London’s total consumption (LU, 2008). Moreover, energy consumption has been identified at 3.4 billion KWh in New York (MTA, 2008) and 1.4 million KWh in Hong Kong (MTR, 2012). The GHG emission coefficient (kgCO$_2$e/Wh) is related to the actual power combination and proportion of fossil fuels used. In general, the GHG emission coefficient with electricity can be estimated by a regional power company or energy management authorities.

The study of GHG emissions from rail transit systems is a popular topic. However, most studies have focused on the benefits of new rail transit projects, and no empirical research has been conducted to evaluate GHG emission benefits that emerge after additional stations are built in existing operational rail transit systems. In this study, a model shift method was used to establish an emission estimation method. The
procedure of this method was different from that used in other studies, and is described as follows:

(A) Consider that a rail transit system is to be constructed, extended, or have the number of stations expanded, and compare it with other private or public road transport systems, such as the car and bus systems.

(B) Calculate GHG emissions according to the existing traffic situation or estimation of the research target with various vehicle types (e.g., cars and buses), and fuel properties, such as gasoline or diesel.

(C) Consider the annual passenger growth rate in the rail transit and intercity road systems to predict annual GHG emission changes, and convert to the cost of purchasing GHG emissions to demonstrate the environmental economic benefits of saving energy and promoting GHG emission reductions.

2. LITERATURE REVIEW
GHG Reduction for the Rail Transit System
GHG emissions from transportation systems can be considered the concept of borrowing the money from bank (Liability). If the road transportation system were replaced by rail transit system, the GHG reduction benefit may be regarded as the bank income concept of GHG emission (Credit). Through the balance and comparison of debt and credit, we can assess whether a rail transit system induces a net reduction of GHG emissions. When the rail transit system is constructed or extended, we expect a change in a region’s GHG emissions. If there are no rail transit systems or additional stations, more cars and buses in the region will emit more GHGs. Therefore, GHG emissions from electric power can be offset by road traffic emissions at the same time.

Some studies have suggested that passenger rail transit systems are a benefit because they increase a region’s population density and encourage users to bicycle or walk over short distances. This reduces the use of cars and buses, and also promotes good health and reduces medical costs (Chen and Hashim, 2016). Moreover, the reduction of travel time can promote economic activity for the gross production demand. Overall, if no rail transit systems are present, the
use of more long-distance vehicles, an increase GHG emissions, and detrimental economic and health effects are present. An outline of this literature review is depicted in Figure 1.

Figure 1. Impact of Rail Transit Systems on GHG emissions (Andrade and D’Agosto, 2016)

The outline in Figure 1 considers the following factors:

(A) Liabilities: A passenger rail transit system (including traction power, stations, and depot) emits GHGs by using electricity. There are two options: one is to consider the overall electric energy consumption due to the operation, and another is to consider only the traction power for train movement. Usually, electric traction energy is 65%–75% of the total electrical energy (Metro, 2014). Moreover, the material consumption and construction activities during the construction stage are also one of the sources of GHGs. This study did not take the GHG emissions from the construction and material procurement of small stations into account because of the difficulty in assessment.

(B) Credit: Items that limit GHG emissions by creating rail transit systems. These items comprise the following:
(1) Model shift: If there is no rail transit system, more private cars and busses are used, resulting in more GHG emissions.

(2) Alleviate traffic congestion: The fewer the vehicles there are on a road, the less traffic congestion there will be.

(3) Land use: Users travel shorter distances, use fewer vehicles, and increase the use of bicycles and walking as connection with rail transit systems. Notably, this item represents the benefits of a higher population density. Most studies have considered only the shift of transportation tools, because the factors of reduced traffic congestion and land-use level were difficult to quantify and incorporate into the scope of assessments. Table 1 lists the GHG emission assessment results of the rail transit systems of various countries in recent years. The results confirmed the reduction effects of GHG emissions after the development of a rail transit system.

Table 1. GHG Emission Reduction Results by the Rail Transit System

<table>
<thead>
<tr>
<th>Rail System</th>
<th>Reduce emissions (ton CO\textsubscript{2}e)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTA- New York</td>
<td>15,000,000/year</td>
<td>(MTA, 2012)</td>
</tr>
<tr>
<td>Los Angeles Metro</td>
<td>12,997,000/year</td>
<td>(MTA, 2012)</td>
</tr>
<tr>
<td>California High Speed Rail (Project)</td>
<td>1,150,000/year</td>
<td>(Chang and Kendall, 2011)</td>
</tr>
<tr>
<td>LGV Mediterranea (Valence-Marseille) (Project)</td>
<td>237,000/year</td>
<td>(Baron, 2011)</td>
</tr>
<tr>
<td>HSR-4500 km-France (Project)</td>
<td>1,000,000/year</td>
<td>(Séguret, 2014)</td>
</tr>
<tr>
<td>THSR Taiwan(Taipei-Kaishung)</td>
<td>656,500/year (2013)</td>
<td>(THSRC, 2014)</td>
</tr>
</tbody>
</table>

3. CONSTRUCTION OF THE GHG EMISSIONS REDUCTION MODEL

After new rail transit stations commence revenue operation, residents can choose the nearest stations within their county and travel by rail instead of driving their cars to neighboring counties, which saves both time and energy. The present research, based on the aforementioned shift mode scenario to
estimate the annual GHG emission variation before and after the construction of new rail stations, includes the following steps.

3.1 Collect Relevant GHG Emission Factors
The following data were collected from the website or Taiwan High Speed Rail Corporation (THSRC) annual reports: GHG emission factors per unit of power (Ef), annual estimated power consumption of the new station (Es), GHG emission factors per rail transit passenger-kilometer (Ec), and GHG emission factors per car or bus passenger-kilometer (PKM).

3.2 Estimate GHG Emission from the Rail Transit System
We calculated the distance between the new stations and the nearby stations, and determined the monthly passengers who traveled from the new stations to nearby stations to estimate the total monthly PKM. Subsequently, the annual PKM was predicted using Equation (1):

\[
P_{ij} \times D_{ij}
\]

where \( P_{ij} \) is the number of passengers traveling from an origin \( i \) to a destination \( j \), and \( D_{ij} \) is the distance between the origin \( i \) and destination \( j \).

3.3 Calculate GHG Emissions From the Rail Transit System
The amount of GHG emissions from the rail transit system were considered for calculating the annual cumulative PKM and the annual electricity use of the new station. We used emission factors to calculate the total amount of GHG emissions.

GHG emissions from the HSR trains and new station operation were calculated using the following equation:

\[
En = PKM \times Ec
\]

where \( En \) is the energy consumption, \( PKM \) is the number of passenger kilometers according to Equation (1), and \( Ec \) is the energy consumption per
PKM.  
Next, GHG($CO_2e$) emissions were expressed with the following two equations:

\[
Emc = En \times Ef \quad (3)
\]

\[
Ems = Es \times Ee \quad (4)
\]

where $Emc$ is the amount of GHG emissions, $En$ is the energy consumption according to Equation (2), $Ef$ is the GHG emission factors per unit of energy, $Es$ is the estimating or actual electric power usage (new station, estimated or actual consumption), and $Ee$ is the GHG emission factor for electricity.

Finally, total GHG emissions from the rail transit system were calculated as follows:

\[
Em(rail) = Ems + Emc \quad (5)
\]

3.4 Estimate the New Station Credit by Assuming a Reduction of Emissions from Cars and Buses, Based on the Proposed Model Shift Values

\[
VKM = [(PKM \times \%vehicle)/L] \quad (6)
\]

where $VKM$ is the total vehicle traveling mileage, $PKM$ is the PKM summation according to Equation (1), $\%vehicle$ is the percentage of PKM shifted from a type of vehicle, and $L$ is the number of passengers travelling by a type of vehicle (load).

For a given time period, the quantity of each fuel consumed ($Qf$) by each type of vehicle can be expressed as follows:

\[
Qf = VKM \times Ed \quad (7)
\]

where $VKM$ is calculated according to Equation (6), and $Ed$ is the unit volume of fuel burned per units of distance traveled.

The corresponding GHG emissions can then be calculated as follows:

\[
Em(road) = Qf \times Ef \quad (8)
\]

where $Qf$ is the quantity of fuel determined in Equation (7), and $Ef$ is the GHG emission factors per unit of fuel.
3.5 Calculate the Annual GHG Net Reduction of Emissions

\[ \text{Em(balance)} = \text{Em(road)} - \text{Em(rail)} \] (9).

4. EMPIRICAL CASE

Three new stations (Miaoli, Changhua, and Yunlin) were added to the Taiwan HSR revenue operation on December 1, 2015. In this study, statistical data were collected from the government website (MOTC 2017) to estimate the annual GHG emission variations before and after the addition of the new stations.

4.1 Estimate the Transferring Distance From New Stations to Nearby Stations

According to monthly traffic statistics reports provided by the traffic unit (MOTC, 2017), we collected the actual quantities \( P_{ij} \) of the passengers who traveled in or out of the new stations in 2016. The number of northbound or southbound passengers was approximately 50% of total passengers. Therefore, we estimated the total annual PKM to the north and south of these three new stations to be 190,021,537 km (Table 2).

<table>
<thead>
<tr>
<th>Three new stations</th>
<th>Interchange stations</th>
<th>Travel distance (km) ( D_{ij} )</th>
<th>Actual quantity of passenger in 2016 (MOTC, 2017)</th>
<th>Estimated annual PKM (X1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miaoli Station</td>
<td>Hsinchu station</td>
<td>32.8</td>
<td>612,906</td>
<td>20,103</td>
</tr>
<tr>
<td></td>
<td>Taichung station</td>
<td>60.8</td>
<td>612,906</td>
<td>37,265</td>
</tr>
<tr>
<td>Changhua station</td>
<td>Taichung station</td>
<td>28.2</td>
<td>529,527</td>
<td>14,933</td>
</tr>
<tr>
<td></td>
<td>Chiayi station</td>
<td>57.6</td>
<td>529,527</td>
<td>30,501</td>
</tr>
<tr>
<td>Yunlin station</td>
<td>Taichung station</td>
<td>52.2</td>
<td>1,016,552</td>
<td>53,064</td>
</tr>
<tr>
<td></td>
<td>Chiayi station</td>
<td>33.6</td>
<td>1,016,552</td>
<td>34,156</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>4,317,969</strong></td>
<td></td>
<td><strong>190,022</strong></td>
</tr>
</tbody>
</table>
4.2 Calculate GHG Emissions of the Rail Transit System

After collecting the relevant data, the 2016 GHG emissions that resulted from running the HSR trains and new stations were estimated to be approximately 8,809 tons (Table 3).

Table 3. GHG Emissions from HSR Trains and New Stations (2016)

<table>
<thead>
<tr>
<th>Three new stations</th>
<th>Interchange station</th>
<th>Estimated annual PKM(X 1000)</th>
<th>GHG emissions (ton) due to Trains running</th>
<th>Actual power consumption (KWh) from Dec. 2015 to April 2016</th>
<th>Prediction of Station's power consumption per year / (KWh)</th>
<th>Station GHG emissions (ton)</th>
<th>estimated annual increasing emissions (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miaoli Station</td>
<td>Hsinchu station</td>
<td>20,103</td>
<td>523</td>
<td>971,520</td>
<td>2,331,64</td>
<td>1,215</td>
<td>1,737</td>
</tr>
<tr>
<td></td>
<td>Taichung station</td>
<td>37,265</td>
<td>969</td>
<td></td>
<td></td>
<td></td>
<td>969</td>
</tr>
<tr>
<td>Changhua station</td>
<td>Taichung station</td>
<td>14,933</td>
<td>388</td>
<td>950,800</td>
<td>2,281,92</td>
<td>1,189</td>
<td>1,577</td>
</tr>
<tr>
<td></td>
<td>Chiayi station</td>
<td>30,501</td>
<td>793</td>
<td></td>
<td></td>
<td></td>
<td>793</td>
</tr>
<tr>
<td>Yunlin station</td>
<td>Taichung station</td>
<td>53,0641</td>
<td>1,380</td>
<td>1,171,10</td>
<td>2,810,64</td>
<td>1,464</td>
<td>2,844</td>
</tr>
<tr>
<td></td>
<td>Chiayi station</td>
<td>34,156</td>
<td>888</td>
<td></td>
<td></td>
<td></td>
<td>888</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>190,022</td>
<td>4,941</td>
<td>7,424,20</td>
<td>3,868</td>
<td>8,809</td>
<td></td>
</tr>
</tbody>
</table>

Note:
1. GHG emission factors per electricity (Ee = 0.521 kg/CO2e (BOE, 2013).
2. Electric consumption of the new station from December 2015 to April 2016 (MOTC, 2017).
3. HSR GHG emission factors Ec × Ef = 0.026CO2e kg/PKM, where Ec is 0.011-L fuel equivalent per KPM (MOTC, 2013) and Ef is 2.36 CO2e (kg/L fuel equivalent).
4.3 Estimate the New Station Credit by Avoiding Emissions From Cars and Buses

We assumed that if no new station was constructed, 100% of the passengers would have driven a car or taken a bus when traveling to neighboring county stations. We referred local traffic survey results in the three counties (MOTCR, 2015) to obtain the journey percentage of the public transportation systems in 2015. Specifically, the journey percentage was 6.6% in Miaoli County, 6.1% in Changhua County, and 5.3% in Yunlin County. Furthermore, we calculated GHG emissions from each station. The 2016 GHG emission avoidance from cars and buses was then estimated to be approximately 14,689 tons (Table 4).

Table 4 GHG Emission Avoidance from Cars and Buses (2016)

<table>
<thead>
<tr>
<th>Three new stations</th>
<th>Interchange stations</th>
<th>Estimated annual mileage (km)</th>
<th>GHG (1) from Private cars (ton)</th>
<th>GHG (2) from public transportation systems (ton)</th>
<th>Total GHG emission if no new station (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miaoli Station</td>
<td>Hsinchu Station</td>
<td>20,103,317</td>
<td>1,465</td>
<td>88</td>
<td>1,552</td>
</tr>
<tr>
<td></td>
<td>Taichung Station</td>
<td>37,264,685</td>
<td>2,715</td>
<td>162</td>
<td>2,877</td>
</tr>
<tr>
<td>Changhua Station</td>
<td>Taichung Station</td>
<td>14,932,647</td>
<td>1,094</td>
<td>60</td>
<td>1,154</td>
</tr>
<tr>
<td></td>
<td>Chiayi Station</td>
<td>30,500,726</td>
<td>2,234</td>
<td>123</td>
<td>2,357</td>
</tr>
<tr>
<td>Yunlin Station</td>
<td>Taichung Station</td>
<td>53,064,014</td>
<td>3,910</td>
<td>186</td>
<td>4,105</td>
</tr>
<tr>
<td></td>
<td>Chiayi Station</td>
<td>34,156,147</td>
<td>2,523</td>
<td>121</td>
<td>2,644</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>190,021,537</td>
<td>13,950</td>
<td>739,</td>
<td>14,689</td>
</tr>
</tbody>
</table>

Note:
1. The journey percentage of private cars was 93.4% in Miaoli County, 93.9% in Changhua County, and 94.7% in Yunlin County (MOTCR, 2015). The private vehicle GHG emission factor (Ed × Ef) is 0.078 CO₂e/kg/PKM [private vehicle Ed is 0.033-L fuel equivalent per PKM (MOTC 2013) and Ef is 2.36 CO₂e (kg/L fuel equivalent) (MOTC, 2013)].
2. The journey percentage of the public transportation systems was 6.6% in Miaoli County, 6.1% in Changhua County, and 5.3% in Yunlin County.
The bus GHG emission factor \( (E_d \times E_f) \) is 0.066 \( \text{CO}_2 \text{e/kg/PKM} \) \[\text{Bus \( E_d \) is 0.028-L fuel equivalent per PKM \( (\text{MOTC, 2013}) \) and \( E_f \) is 2.36 \( \text{CO}_2 \text{e} \) (kg/L fuel equivalent) \( (\text{MOTC, 2013}) \)].

### 4.4 2016 GHG Net Emissions

As revealed in Table 5, the new stations increased the number of transferring passengers choosing local stations instead of using cars or buses directly. The results indicated that approximately 5,880 tons of GHG emissions were credited to the three new HSR stations after balance.

<table>
<thead>
<tr>
<th>Three new Stations</th>
<th>Annual GHG emission without 3 new HSR Stations Em(road) (ton/year)</th>
<th>Annual GHG emission with 3 new HSR Stations Em(rail)(ton/year)</th>
<th>Em(balance) (ton/ year )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miaoli Station</td>
<td>4,429</td>
<td>2,706</td>
<td>1,723</td>
</tr>
<tr>
<td>Changhua Station</td>
<td>3,511</td>
<td>2,370</td>
<td>1,140</td>
</tr>
<tr>
<td>Yunlin Station</td>
<td>6,749</td>
<td>3,732</td>
<td>3,017</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14,689</strong></td>
<td><strong>8,808</strong></td>
<td><strong>5,880</strong></td>
</tr>
</tbody>
</table>

### 4.5 Estimated Future Carbon Reduction and Carbon Cost Savings

Scenario 1: We assume the number of passengers using the three new stations will grow by 2% annually and the percentage using public transportation systems (6.6% in Miaoli County, 6.1% in Changhua County, and 5.3% in Yunlin County, respectively) to be the same as that in 2015. The current international carbon transaction costs are approximately average 30 USD per ton \( (\text{Bank, 2016}) \). The reduction quantities per year of GHG emissions are expected to gradually increase from 5,880 tons to 8,995 tons during 2016–2030 operations, and the cost savings on carbon rights is expected to increase from 1.76million USD to 2.7million USD per year (Figure 2).
Scenario 2: We assume that if the government promotes intercity public transportation systems, the passenger utilization rate will be enhanced by approximately 1% annually. GHG emissions are thus estimated to increase from 5,880 tons to 8,550 tons during 2016–2030 operations at the three new stations, and carbon transaction cost savings are expected to increase from 1.76 million USD to 2.57 million USD (Figure 3). These results are slightly lower than those in Scenario 1, and indicate that the carbon reduction benefits of intercity public road transportation systems are limited in comparison with those of a rail transit system.

Figure 2. GHG Emissions and Cost Saving Estimation for the Three New HSR Stations if the Number of Passengers Increased by 2% Annually
5. Conclusion and Suggestions

This study utilized the concept of emission mode shift to establish a GHG emission estimation method and calculate the GHG emissions of three new HSR stations in Taiwan. Various factors were considered, such as the increase of GHG emissions caused by the new station’s electricity demand (debit) and by the trains carrying passengers from the new stations to nearby stations (debit), and the relative avoidance caused by a reduction in the use of private cars and public buses (credit).

According to the results, the amount of GHG emissions avoided by rail transit systems (credit) was higher than that induced by the new stations and traction electricity demand (debit). Furthermore, the carbon reduction benefits of intercity public transportation by the road system were limited in comparison with those of the rail transit system. To optimize environmental economy, it is recommended that the government can invest in local public transportation systems so that residents can easily use the intercity rail
transit system; this will save the travel time, and can help prevent the possibility of a traffic jam on local roads and highways.

The calculation model of GHG emissions provides a reference for evaluating the sustainable benefits of future stations or additional rail lines, and may help convince the people to attain GHG reduction goals set by the government.

In the future, different scenarios should be analyzed to account for various transfer rates and the percentage of private cars and public buses used, to identify novel efforts for GHG reduction.

6. References


BOE (2013). "Electrical Emission GHG Coefficient." Bureau of Energy Available online: file:///C:/Users/user/Downloads/103%E5%B9%B4%E9%9B%BB%E5%8A%9B%E6%8E%92%E6%94%BE%E4%BF%82%E6%95%B8%E5%85%AC%E5%91%8A%20(2).pdf (accessed on 10 June 2016).


