Announcement from Editorial Board

The article henceforth has been retracted based on the investigation on the complaints received against it.

Title: Green Transport Infrastructure of Taiwan
Author: Shyi-Min Lu, Ching Lu, Yu-Shun Huang

The first author Mr. Shyi-Min Lu has published the article without Mr. Yu-Shun Huang's authorization. In addition, a large part of the article is judged to be plagiarized from Mr. Yu-Shun Huang's M.S. thesis.

The scientific community takes a very strong view on this matter and treats all unethical behaviors such as plagiarism seriously. Hence the article, which is published in OJEE Vol.2 No.1, 16-21, 2013, has been removed from this site.

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Green Transport Infrastructure of Taiwan

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ABSTRACT

Transport is the lifeblood of a nation's economy. Since the fossil fuels are being gradually depleted and the global warming phenomena are more and more serious, this article is to construct a low-carbon transport infrastructure for Taiwan by the implementation of energy-saving measures. First of all, via data collection and analysis, we found that the small passenger cars and the large trucks are the largest energy users in the transport sector, due to their high energy intensities and large transport volumes. Therefore, their energy-conserving potentials are the focuses of this study. According to "Top-Down" methodology, the most effective and economical energy-saving strategies for Taiwan's transport sector are the significant adoptions of rail transport and electrification mode. Whereby, under a maximal energy-saving scenario, comprising of delicate shift of transport volumes, the energy saving potential in the land transport sector of Taiwan is 4914 MLOE (million liters of oil equivalent), which is equivalent to greenhouse gas reduction of 10.56 Mt-CO_{2e} approximately with a scale of 45.3% of crediting for 4.1% reduction of national GHG emissions. Finally, we suggest the green transport infrastructure of Taiwan should be mainly comprised of rail transport, electric motorcycles, MRT (Mass Rapid Transit), and EV (Electric Vehicles).

Keywords: Land Transport Sector; Low-Carbon Infrastructure; Energy Conservation

1. Introduction

Please refer to **Table 1**. Taiwan's total energy use in the transport sector was 15546.3 MOEL in 2010 [1], accounting for 12.92% of the national final energy use. In addition, the transport sector totally emitted 35.317 Mt-CO_2 [2] in 2010, with a share of 13.9% of national GHG emissions. Based on the calculation of these data, the carbon intensity of the transport sector is 0.00227 Mt-CO_2/MLOE, while that of entire nation is 0.00211 Mt-CO_2/MLOE. The possible explanation for the closeness of these two values may be that half of Taiwan's primary energy supply is from crude oil and petroleum products. Meanwhile, the land transportation, consuming 81.3% of energy in the transport sector, should be sufficient to represent the entire transport sector, in terms of energy saving and carbon reduction.

As shown in **Table 2**, the industrial sector—the primacy of oil consuming structure—used 48% national petroleum in 2010 mainly for the manufacture of chemical raw materials and relative products. The transport sector, on the second place, with share of 30%, mainly used energy in the forms of vehicle fuels, including 9722.1 million liters of gasoline and 4414.0 million liters of diesel.

2. Energy Saving Strategies for Taiwan's Land Transport Sector

Please refer to **Table 3**. Pursuant to transport objects, the "land transport" can be divided into two kinds of "manned transport" and "freight"; the total energy consumption of the former is about twice the latter's. The small passenger cars use 70% of energy in the manned transport, accounting for 50% by taking the transport sector as a whole. In other words, the small passenger cars use one-tenth of Taiwan's petroleum. Therefore, we regard the small passenger cars as the major energy-saving objects in the transport sector. The concrete measure is to travel more frequently by rail transports that include railway, high-speed rail and MRT (Mass Rapid Transit) instead of driving cars, while the remaining cars are made to be converted to electric vehicles to the maximal extent. As shown in **Table 3**, in terms of energy intensity, the electric vehicle is 50% of that of small passenger car, while the rail transport is as low as 13%. Here, the unit of energy intensity is LOE/p-km (*i.e.*, liters of oil equivalent per person per kilometer). The correspondingly energy-saving measure for the second largest energy user—motorcycle—is to encou rage people taking MRT

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Table 1. Energy consumption structure of the transport sector of Taiwan in 2010.

Energy resource	Oil products						Power	Total
Fuel type Unit Transport way	LPG (Million liter)	Gasoline (Million liter)	Aviation fuel (Million liter)	Diesel (Million liter)	Fuel oil (Million liter)	Energy use subtotal (MLOE)	(MLOE)	(MLOE)
International aviation	-	-	2473.9	-	-	2199.1	-	2199.1
Domestic aviation	-	-	96.4	-	-	85.7	-	85.7
Road	133.1	9722.1	-	4414.0	-	12643.9	-	12643.9
Railway	-	-	-	31.9	-	29.7	286.7	316.4
Domestic water	-	-	-	111.5	184.8	301.2	-	301.2
Total	133.1	9722.1	2570.3	4557.4	184.8	15259.6	286.7	15546.3

Data source: [1].

Table 2. Domestic oil products consumption.

Year	1990		2000		2010		1990-2010
Energy use unit and percentage Item	MLOE	%	MLOE	%	MLOE	%	Annual growth rate (%)
Power generation	5652.9	19.5	7484.1	17.0	3322.4	6.4	−2.6
Power plant's self use	1819.8	6.3	2384.6	5.4	2006.8	3.9	0.5
Industry	7799.8	26.9	12709.1	28.8	24810.0	48.0	6.0
Transport	7958.9	27.4	14316.3	32.5	15259.6	29.5	3.3
Agriculture	1047.3	3.6	844.3	1.9	338.5	0.7	−5.5
Service	1225.6	4.2	1000.8	2.3	1150.2	2.2	−0.3
Residence	1240.2	4.3	1631.7	3.7	1317.5	2.5	0.3
Non-energy use	2261.9	7.8	3718.0	8.4	3513.1	6.8	2.2
Total (domestic use)	29006.5	100.0	44088.8	100.0	51718.2	100.0	2.9

Data source: [3].

Table 3. The energy intensities of land transportations for 2010 and 2030.

	Year	2010				2030	
		Technical Scenario	Energy intensity	Transport volume	Energy use	Energy-saving measure	Energy intensity
	Unit	-	LOE/p-km	Million person-km	MLOE	-	LOE/p-km
Manned transport	Motorcycle	Internal combustion engine	0.0241	66,795	1610	Electrification mode and rail mode	0.0124
	Car		0.054	99,394	5367		0.027
	Bus		0.024	15,843	380		0.016
	Railway	60% loaded	0.011	8998	99		0.007
	MRT Taipei	88% loaded	0.011	4237	47	Expanding transport volumes: fully loaded, increasing number of runs and lines.	0.01
	MRT Taichung	-	-	-	-		0.01
	MRT Kaohsiung	50% loaded	0.027	201	5		0.01
	High speed rail	49% loaded	0.015	7491	112		0.0075
	Others	-	-	88	40	-	-
	Subtotal	-	-	203,047	7661	-	-
Freight	Unit	LOE/t-km		Million ton-km	MLOE		LOE/t-km
	Railway	0.025		873	22	Expanding transport volume	0.025
	Large truck	0.046		57,614	2650	Rail mode	0.025
	Small truck	0.18		2900	522	Hybrid mode (HEV)	0.1439
	Subtotal	-		61,387	3194	-	
	Total	-		-	10855	-	

Data source: bureau of energy MOEA, ministry of transportation and communications.

or riding electric motorcycle, because their energy intensities are only half.

Basically, for the same transport volume, the energy used by rail transport is only 13% - 19% of traditional car's or 50% of electric vehicle's. Apparently, among the manned transports, the rail transport is more energy-efficient than electric car and of course much more energy-efficient than traditional vehicle. Moreover, for the transport sector to meet the goals of energy conservation and carbon reduction, it would be much more economical and feasible by increasing the number of runs of the rail transports, instead of purchasing gigantic amount of electric vehicles additionally, because there are already many kinds of rail transports in Taiwan, like, the high-speed rail, Taiwan Railway and MRT. But motorcycle is not the case, because the MRT is almost as energy efficient as electric motorcycle in terms of energy intensity 0.01 LOE/p-km and 0.0124 LOE/p-km respectively while that of traditional motorcycle is 0.0241 LOE/p-km. Therefore, the MRT and electric motorcycle are as twice energy-efficient as traditional motorcycle. But due to personal convenience, motorcycle is very popular in Taiwan. Impressively, every Taiwanese owns 0.64 unit of motorcycle [4,5]. Therefore, traditional motorcycles have 33% transport volume but only use 21% energy in the manned transport sector. Motorcycles do contribute significant energy conservation in Taiwan's transport infrastructure. So basically in the manned vehicles, the main energy-saving measure for the small passenger cars should concentrate on transferring their transport volume to MRT, while that for traditional motorcycles is mainly on their electrification mode.

Please refer to **Table 3**. As for freight sector, the main energy users are large trucks with transport volume share of 83%. However, in the unit of liters of oil equivalent per ton per kilometer (LOE/t-km), the energy intensity of large truck is twice that of rail transport (e.g., Taiwan Railway). On the other hand, the energy intensity of small truck is remarkably high, about four times that of large truck and seven times that of Taiwan Railway. Obviously, railway transport has significant energy-saving advantage over the traditional trucks. However, railway has very low transport share (1.4%) in Taiwan's freight sector. Therefore, the proposed energy-saving measure for freight is to shift the majority of large trucks to railway. In addition, in small trucks, the internal combustion engines should be converted to electric motors, because the energy consumption could be lowered by 20%.

3. Energy-Saving and Carbon Reducing Program for Taiwan's Land Transport

As shown in **Table 4** and **Figure 1**, among many planning programs, we only illustrate the most energy-saving one—"1) maximizing the MRT; 2) increasing the number of runs of high-speed rail and Taiwan Railway; and 3) partly electrifying the motorcycles"—as this article's "the best energy saving and carbon reducing program for the manned transport sector of Taiwan from 2010 to 2030", which is highlighted as follows.

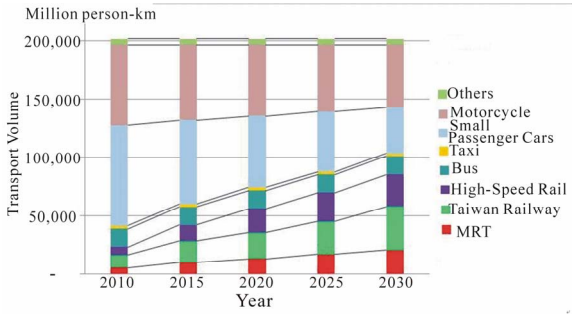

Figure 1. Transport volume distribution of manned vehicles from 2010 to 2030.

1) Expanding the operations of Taipei MRT to 3 times that of 2010;

2) Expanding the operations of Taichung MRT to 2 times that of 2020; two operation lines will be completed for Taichung MRT in 2020, the transport volume of which is assessed based upon the growing background of Kaohsiung MRT;

3) Expanding the transport volume of Kaohsiung MRT to 3 times that of 2010;

4) Expanding the transport volumes of Taiwan Railway and high-speed rail to 1.8 times and 2 times respectively those of 2010, the concrete measures of which are the increase of number of runs;

5) Transferring the reduced transport volume of small passenger cars to the high-speed rail and Taiwan Railway; meanwhile, transferring the reduced transport volume of motorcycles to MRT, as described in the above; and 80% remaining transport volumes of buses, cars and motorcycles are all practiced with electrification mode.

In this article, we adopt the "Top-Down" analytic methodology. Therefore, the data shown in **Table 3** all come from the government departments, for example, Ministry of Economic Affairs and Ministry of Transport and Communications. Here, we use the "million personkm" as the unit of transport volume of manned vehicles and "million ton-km" for the freight transports. As shown in **Figures 1** and **2**, basically, the respective total transport volume in "manned sector" and "freight sector" remains unchanged from 2010 to 2030. Under the transfers of transport volume between various means of transport, the total transport volume in 2010 is same as that in 2030, but the distribution is different. In other words, the transport volumes of less energy-efficient vehicles are transferred to more energy-efficient vehicles, whereby the total energy use is reduced.

As shown in **Table 4**, according to above program, the

Table 4. Energy saving program and results of Taiwan's land transport sector for 2030.

	Year	2030			
		Transport's energy-saving measures in the base year of 2010	Transport volume	Energy use	Energy-saving volume
	Unit	-	Million person-km	MLOE	MLOE
Manned transport	Motorcycle	Partly transferring transport volume to MRT, and electrifying the 80% remaining transport volume	54,579	804	805
	Car	Partly transferring transport volume to railway and high speed rail, and electrifying the 80% remaining transport volume	58,312	1942	3425
	Bus	Electrifying the 80% transport volume	15,843	279	101
	Railway	1.8 times the fully-loaded transport volume	26,995	189	−90
	MRT Taipei	Triple the fully-loaded transport volume	14,445	144	−98
	MRT Taichung	Double the fully-loaded transport volume of 2020	1004	10	−10
	MRT Kaohsiung	Triple the fully-loaded transport volume	1205	12	−7
	High speed rail	Double the fully-loaded transport volume	30,576	229	−117
	Others	-	88	84	−44
	Subtotal	-	203,047	3694	3967 (51.8%)
	Unit	-	Million ton-km	MLOE	MLOE
Freight	Railway	Expanding transport volume by the 80% transport volume of large truck	41,983	1050	−1028
	Large truck	80% transport volume transferred to railway	16,503	759	1891
	Small truck	80% transport volume transferred to HEV	2900	438	84
	Subtotal	-	61,387	2247	947 (30%)
	Total	-	-	5941	4914 (45.3%)

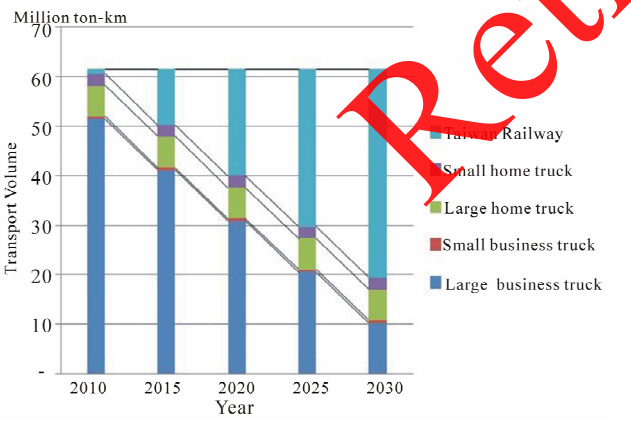

Figure 2. Transport volume distribution of freight transportations from 2010 to 2030.

transport volume decreased from motorcycles is the transport volume increased to MRT. The same strategy is practiced to small passenger cars and rail transports. No surprise, the energy-saving amount of small passenger cars—up to 3425 MLOE—almost covers the total energy-saving amount in the entire manned transport sector. Additionally, as shown **Figure 3**, the energy-saving scale is up to about 50% significantly by taking the manned transport as a whole.

As shown in **Table 4**, the transport volume of small passenger cars is effectively transferred to Taiwan Railway and high-speed rail. Although the volume of rail transport is increased significantly, the net energy-saving amount is remarkable, due to the super low energy-consuming intensity of rail transport. Under the electrification mode, the increasing rate of electric vehicles for the purpose of replacing cars and motorcycles—will be 20% in every five years, making this program very effective in energy conservation, because the original transport volumes of cars and motorcycles are gigantic.

Next, please refer to **Figure 2** and the left lower fields of **Table 4**. "The best energy-saving and carbon-reducing program for the freight transport sector of Taiwan from 2010 to 2030" is highlighted as follows.

Transferring 80% freight volume of large truck to Taiwan Railway. Converting 80% small trucks to hybrid trucks.

Please refer to the lower half of **Table 3**. According to the data provided by the Institute of Transportation, MOTC, the large truck consumes about 1 liters of diesel, after traveling 1 kilometer with 20 tons of load. Meanwhile, the small truck consumes 1 liters of gasoline, after

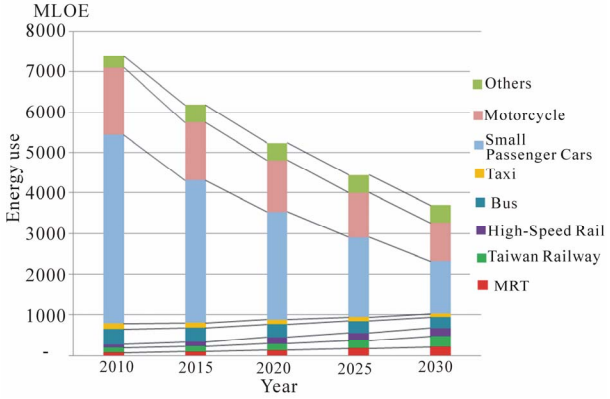

Figure 3. Energy use trend of manned vehicles from 2010 to 2030.

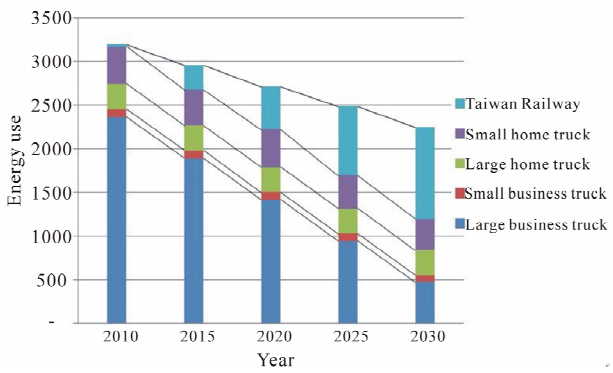

Figure 4. Energy use trend of freight transportations from 2010 to 2030.

traveling three kilometers with 1.8 tons of load. Therefore, the energy intensities of large truck and small truck are 0.046LOE/t-km and 0.18LOE/t-km respectively.

As shown in **Table 4**, if transferring most road freight volume to Taiwan Railway, the energy consumption could be reduced significantly. Taiwan Railway is almost the only main long-distance intercity transport (*i.e.*, more than 50 kilometers) to energy-efficiently replace the large trucks. Therefore, in this program, 20% freight of large trucks in 2010 is transferred to Taiwan Railway in every five years. As for small truck, the main energy-saving measure is focused on HEV. Please refer to the reference [6]. There will be an energy saving of 20%, after the small truck is converted to HEV (Hybrid Electric Vehicle). Therefore, the freight energy saved from replacing the small truck with HEV at a rate of 20% in every five years can be calculated in the period between 2010 and 2030.

As shown in **Table 4** and **Figure 4**, under the scenario significantly reducing the freight volume of large trucks and remarkably increasing the freight volume of Taiwan Railway, the calculation results that the energy consumed in the freight sector can be amazingly reduced 947 MLOE by deducting the inferred 2247 MLOE in 2030 from the original 3194 MLOE in 2010.

4. Conclusions and Discussion

Please refer to upper half of **Table 3**. The energy-using share of the small passenger cars is about 50%, followed by 25% of the large trucks, by taking the entire land transport sector as a whole. It may deduce that the energy-saving results of small passenger cars and large trucks are crucial to the carbon-reducing credits of the entire transport sector. As shown in **Table 4**, after adopting the program: 1) maximizing the MRT; 2) increasing the number of runs of Taiwan Railway and high-speed rail; and 3) partly converting the motorcycles to electrification mode; it is possible for the manned transport sector to save energy up to 3967 MLOE or 51.8%.

There are two measures for the energy-saving program of mall passenger cars: the first is to transfer 41.3% transport volume to Taiwan Railway and high-speed rail; the second is to convert 45.0% transport volume to electrification mode. According to the calculated results, the energy-conserving shares will be 56.0% and 35.2% respectively. Obviously, the rail mode is remarkably superior to the electrification mode.

Please refer to the lower half of **Table 4**. On the aspect of freight transport, when shifting the large truck to Taiwan Railway and converting the small truck from fossil-fueled mode to hybrid mode respectively at a ratio of 80% in terms of transport volume, the total energy saving will be 947 MLOE or 30%. Wherein, the energy saving of the largest energy consumer—the large truck—is up to 1891 MLOE or 70%. But overall, the effectiveness of the energy-saving is limited, because at the same time, the energy consumed by Taiwan Railway increases 1006 MLOE significantly. However, as mentioned above, in the energy saving measures of rail mode, the only one thing needed to do for the Taiwan Railway is to increase the number of runs. From the economical point of view, it is still very worthy.

From above analyses, the total energy saving amount of both manned and freight transports is 4914 MLOE, which is equivalent to GHG reduction of 10.56 Mt-CO_2 approximately with a scale of 45.3%. Meanwhile, the resulted shares are 4.08% and 4.15% respectively on the national aspects of energy conservation and carbon reduction.

Finally, from above data analyses and results discussion, we suggest two green strategies for the land transport sector of Taiwan. First of all, the extensive adoption of rail mode, including the increase of number of runs and the expansion of transport volumes, is the most effective energy-saving measure, particularly for the small passenger cars and large trucks that should be replaced by rail transport in a large scale. Secondly, as the popularity of motorcycles in Taiwan, instead of being replaced

by rail transport completely, we suggest the adoption of electric motorcycle should be more feasible and economical, due to the considerations of personal convenience and dense population in Taiwan.

5. Acknowledgements

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