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Data Envelopment Analysis on Energy Efficiencies of Transport Modes in Iskandar Malaysia Region

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Abstract The goal of this paper is to assess and evaluate the annual productivity of transport modes in Iskandar Malaysia with the aim of discovering the inefficient year. Transport mode is one of the energy-consuming sectors. The paper used Data Envelopment Analysis (DEA) technique to achieve this purpose. It also employed multiple linear regression approach to estimate future energy performance. Spearman's correlation coefficient revealed that the relationship between the variables selected is isotonic, and it shows there is a perfectly positive relationship between the variables selected. Hence, DEA results revealed that in the year 2005, efficiency, achievement was achieved under variable return to scale, but was not in 2005 under constant return to scale assumptions. The excess energy and shortfalls in productivity were highlighted. Besides that DEA set targets for improving productivity.

Keywords Energy efficiency, carbon dioxide emissions, transportation sector

2010 Mathematics Subject Classification 90B06; 91B76

1 Introduction

Transportation is the movement of people and goods from one place to another. A typical mode of transport includes air, road, rail, water and pipeline. In this paper, we looked at land transport in Iskandar Malaysia (IM) only. Passenger transport and Freight transport were considered. Passenger vehicles that ply on roads such as buses, motorcars, and motorcycles are passenger transport while goods vehicles and railway make the freight transport. These two modes of transport play important roles in economic growth and globalization, but most types consume large amount of fossil fuel, which causes air pollution. The consumption is likely to grow up further with a rapid increase in the population and industrialization and urbanization. Agricultural activities increase freight transport demand, and higher real income stimulates leisure-related travel, which invariably increases passenger transport demand.

There exists inadequate possibility for mitigation measures in the short run before the year 2025 runs out. Transport Demand Management(TDM) is the primary counter mitigation measure that is available in the transport sector. According to IM report [1], it is expected that by 2025 the contribution of TDM to reduction in GHG will be 2.5% for IM region alone. Areas such as energy-efficient vehicles and diffusion of biomass will require incentives such as subsidy and tax reduction, empowering local Authorities to take effective measures in TDM and preservation of renewable energy. In order to bring this percentage to zero levels, the IM Comprehensive Development Plan (CDP) has to be reviewed to have new and bold policies that could encourage and promote business and citizen to take these counter measures. This could only be achieved in the long run. Hence, this sector can aggravate large foreign exchange burden by demanding huge oil imports and soar green house gas (GHG) emissions.

Consequently, it is necessary to understand the difficulties associated with this sector: among which are fuels shifting from oil to natural gas and biofuel, changes from car to bus and railway, conservation potentials, performance and their trends, and so on. In this regards, the purpose of this research is to address some key policy questions regarding the transport sector in IM.

- What is the physical and operational difference witnessed in the past, in terms of transport performance, energy demand, and Green House Gas (GHG) emissions?
- How would energy consumption, GHG emission's response to changes in the future?
- What are the alternatives and precautions to ensure availability and sustainability?
- How can those alternatives and precautions be carried out?

To answer these questions objectively, we look back at the performance trend of a transport sector in IM and assess it critically. The likelihood impacts of ongoing trends are estimated by simulating past and transport sector input and output using Compound Annual Growth Rate (CAGR) approach. A further simulation shows significant growth in the transport performance, and hence is likely to influence large oil consumption and carbon dioxide emissions from this sector. The consequences of certain policy and mitigation measures to maximize output (kilometer coverage) subject to minimization of energy demand and GHG emissions are studied using DEA. At the end of the analysis, a discussion on the policy options available to address these questions raised was made.

2 Overview of Transport Sector Performance in IM

A Modal share is defined as a percentage of the trip taken via public transport modes during the 7-9 AM peak periods. Modal share in passenger percentage in IM is estimated from Japanese International Co-operation Agency (JICA) and Malaysia Traffic Survey. The modal share of IM passenger is estimated from the survey on integrated urban transportation strategies for environmental improvement in Kuala Lumpur known as JICA, whereas that of freight is estimated from the freight transport demand. Mass transit is referred to public transport. A public transport is a shared passenger transportation service that is available for use by the general public, as distinct from modes such as taxicab, car pooling or hired buses, which are not shared by strangers without private arrangement. Examples of mass transit in IM are Causeway-links buses, Trinition buses, JB central line buses etc.

A freight service provisions in IM is mostly pronounced by goods vehicles. For example, in 2005 alone 99,836 goods vehicles were registered in IM, which grew at the rate of 8.76% per annum [2]. Total freight service performance stood at 1.652 TKM, which translates into 99.4% in that year. If this figure increases annually at a compounded growth rate of 5.62% under (BaU) scenario, it will reach up to 5.204 TKM by 2025. However, railway freight service in 2005 was 0.011 TKM, which represent only 0.60% of freight service performance. The total energy demand by freight transport stood at 572 million ton in the same year. If this figure continues to grow under BaU scenario at the rate of 1.81%, it will reach up to 1,442 by 2025. GHG emissions in 2005 stood at 1,615 ktoe, if this increases at 4.50% annually this will clock up to 4,070 ktoe by 2025.

In 2005 [2], statistics show that 836,777 motorcars, 1,060,431 motorcycles, 388 buses, 10,989 taxis and 39,220 other vehicles were registered in IM (see Table 1). Performance of passenger transport in 2005 stood at 0.3816 PKM, if this grows at an annual rate of 3.99% under BaU scenario. It will reach up to 0.8677(PKM) by 2025. Energy demanded in 2005 is 359 Ktoe. If this figure is simulated 21 times at a compound annual growth rate of 3.83% per annum (p.a) 790 ktoe will be obtained, whilst GHG emission was 1,015 ktoe, if this figure grows at 2.41% p.a, after 21 years, it will clock up to 1,672 ktoe under BaU scenario. In both the freight and passenger transport, we have noticed a tremendous growth in terms of performance, energy demand and green house gases emissions. During the year 2005, IM transport, sector (freight and passenger) consumed 925 ktoe of petroleum (about 99.4% of total transport energy demand in that year), 6 ktoe natural gas (0.6%). Analysis of the aforementioned data indicates that petroleum products accounts for the major energy demand in the transport sector in 2005. Specific direct energy demand and GHG emissions were estimated for different freight and passenger transport modes.

Table 1: Freight and Passenger Transport Statistics in IM

Detail	Transport	2005	%
Freight in billion(TKM):			
	Railway	11	0.60
	Good-vehicle	1,642	99.40
Passenger in billion(PKM):			
	Buses	65	1.87
	Railways	23	0.66
	Motorcars	374	68.47
	Motorcycles	1,005	40.71
Total number in IM:			
	Motorcars	836,777	0.41
	Buses	8,388	4.86
	Goods vehicles	99,836	51.59
	Motorcycles	1,060,431	51.59
	Taxis	10,989	0.53
	Others	39,220	1.91

3 The Basic Idea on Slack Based Model(SBM)

Measuring productivity has some important benefits. Among the benefits are its ability to identify dimensions on which to improve productivity. It can give useful information to the management of DMU. More so, it provides a target to guide future operations [3, 4]. DEA provides an approach for achieving efficient targets for inefficient operations [5]. The input oriented DEA models consider the possible ratio input reductions while maintaining the current levels of outputs. The output oriented DEA models consider possible ratio output augmentations while keeping the current levels of inputs [6]. In order to consider both input decreases as well as an output increase simultaneously. The productivity measurement approach used in this paper adopts the slack based DEA model [7], which focuses on the two-stage process that can identify inefficiency in the forms of inputs and outputs slack. The SBM shows that these input and output slacks can be optimized directly to identify the DEA efficient frontier.

3.1 Mathematical Presentation of SBM

Consider the set of n DMU. For DMU_j consumes varying amounts of m different inputs to produce s different outputs. Specifically, DMU_0 consumes an amount x_{i0} of input i and produce an amount y_{r0} of output r. We assume that $x_{ij} \geq 0$ and $y_{rj} \geq 0$ and further assume that each DMU_j has at least one positive input and one positive output value. The model is based upon input and output slacks. We present the model below:

$$\left.\begin{aligned} &\max \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \\ &\text{subject to} \\ &\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{i0}, \quad i = 1, ..., m \\ &\sum_{j=1}^{n} \lambda_j y_{rj} + s_r^+ = y_{r0}, \quad r = 1, ..., s \\ &\lambda_j, s_i^-, s_r^+ \geq 0 \end{aligned}\right\} \tag{1}$$

Note:

(i) If $\sum_{j=1}^{n} \lambda_j = 1$ is added, the resulting model becomes Variable Return to Scale(VRS).

(ii) If $\sum_{j=1}^{n} \lambda_j \leq 1$ is added, the resulting model becomes Non Increasing Return to Scale(NIRS).

(iii) If $\sum_{j=1}^{n} \lambda_j \geq 1$ is added, the resulting model becomes Non Decreasing Return to Scale(NDRS).

SBM is sometimes called additive DEA model. It assumes equal borderline deserving of the non-zero input and output slacks. The SBM is a unique appropriate index, since it is neither input-oriented nor output oriented. Rather, it simultaneously minimizes input while maximizing output [8,9]. SBM maximizes the sum of all input and output slacks. The inputs are reduced proportionately, and the outputs are increased in different proportions. Model(1) identify a Constant Return to Scale (CRS) frontier, and therefore, is called CRS SBM. If (i) is added to Model (1) the resulting model identifies a VRS frontier. On the other hand, if (ii) is added to (1) the resulting model identifies NIRS frontier and if (iii)) is added to (1) the result identifies NDRS frontier.

3.2 Geometric Presentation of Slack Based Model

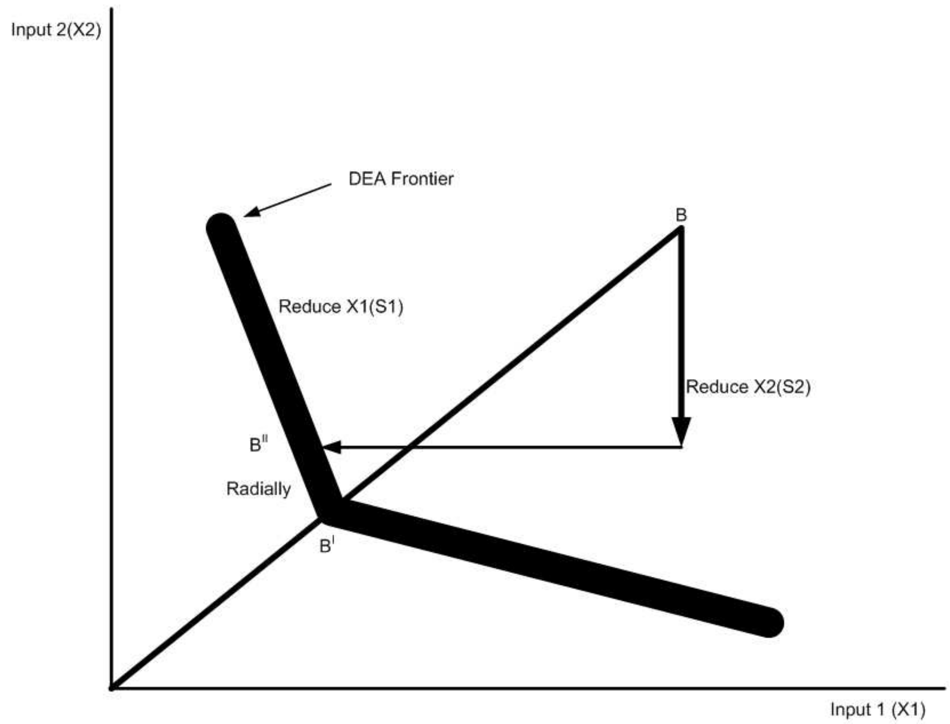

Figure 1: Additive DEA Model

Geometrically the additive model can be shown as in Figure 1. Let's assume there are two inputs and one output. Furthermore, let's assume there are three DMUs represented by B, B^1 and B^{11}. The DEA frontier is represented by the thick line. Obviously, two DMUs (i.e. B^1 and B^{11}) are efficient, whilst DMU, B is inefficient. Application of the basic CCR input oriented model [5] would radially reduce input one by $X1$ amount and input two by $X2$ amount respectively, in order to project DMU, B to a point B^1 on the DEA Frontier. However, since the additive model is neither input-oriented nor output -oriented, when it is applied. It reduces the first input slack by $S1$ amount and the second input slack by $S2$ amount and maximizes the output slack simultaneously, hence, projecting the DMU, B at a point B^{11} on the DEA frontier. That gives us a new projection. We employed Compound Annual Growth Rate (CAGR) approach [10] to simulate data from 2005 to 2025 projections, and used the data to perform regression analysis. The compound growth rate model is presented below:

$$CAGR = \left[\frac{y}{x}\right]^{1/n} - 1 \tag{2}$$

where y = future value, x = present value and n = number of years

3.3 Data

The principal source of data is a project entitled Low-carbon City 2025 Sustainable IM [1]. This document came out as a result of a research Group 7 of Vice Chancellor Council-Japan Society for the promotion of science (VCC-JSPS). The main collaborators in the research project are Universiti Teknologi Malaysia(UTM) and Tokyo University. Other partners involved in the research work are Toyohashi University of Technology, Ritsumeikan University, and Okayama University. It should be noted that the data was collected for only one year (2005). Other sources of data include Railway Yearbooks [11], Yearbook of Statistics [2], and State/District Data Bank of Statistics [12].

Years are used as decision making units (DMUs) and energy consumed and carbon dioxide emission in million tons (kte) serves as our inputs. Performance measurement of freight transport (TKM) p.a and that of passenger, transports (PKM) p.a were used as outputs. This information was simulated for 21 years in line with the project's target of 2025. Pollutant is treated as undesirable attributes in the sense that we wish to increase the desirable attributes and decrease undesirable attributes. As pointed out by [13], the advantage of keeping the number of inputs x and outputs y small relative to the number of DMUs is that as the ratio $(y + x)/n$ rises, the ability of the DEA to be discriminated among DMU falls significantly, since it becomes more likely that any given DMU will find some set of output and input weights, which will make it appear efficient.

Table 2: Trend in Transport Performance

Year		Roadway (bill.)	Railway (bill.)
2005:			
	TKM	1.642	0.011
	PKM	3.444	0.023
2025:			
	TKM	5.171	0.033
	PKM	8.899	0.222

The paper used slack base DEA model with freight and passenger transport for different years as DMUs. Performance in terms of TKM serves as outputs. Energy consumption and carbon dioxide emissions serve as inputs. The analysis assumes constant return to scale (CRS), although the results with variable return to scale (VRS) yield different results. The reason is obvious, VRS measures only technical efficiency, whilst CRS efficiency accounts for both technical efficiency and efficiency loss when the DMU does not operate in its most productive scale size [14, 15].

The discussion of the most important trends of the transport sector obtained after collecting these data is presented in Table 2. The Table shows the trend in transport performance between roadways and railways. It can be seen from the table that railway activities are not use widely used as a means of freight in IM region.

Table 3 shows the summary data in descriptive statistics. The measures of central tendency such as average and standard deviation against their respective input and output variables are shown in the table. The range of the variables including the maximum value

Table 3: Descriptive Statistics of the Inputs and Outputs Variables

	Energy	GHG	TKM(PKM)
Max	1,379.5(761.29)	3,894.9(1,634.23)	4,931.0(8,345.26)
Min	572(359.00)	1,615(1,015.00)	1,625(3,816.00)
Mean	920.1886(536.43)	2,598.08(1,301.35)	3,013.13(5,802.88)
SD	243.52(121.45)	687.57(187.26)	986.78(1,367.03)

Figures in parenthesis indicate passenger transport

and minimum value are also shown against its corresponding variables in the table. The figure outside the bracket represents the freight transport mode, whilst the figure inside the parenthesis represents passenger transport.

Table 4: Spearman's Rank Order Correlation Coefficient of Inputs and Outputs

Outputs		TKM	PKM
Inputs:			
	Energy	0.9996	0.9999
	GHG	0.9996	0.9992

Table 4 shows the results obtained from the spearman correlation coefficient. After selecting input and output variable, Spearman's correlation coefficient analysis is tested to ascertain whether variables have isotonic relationship, i.e. decreasing input increase efficiency and increasing output increases efficiency. As shown in Table 4, all the variables selected are positively correlated.

4 Results

Multiple regression analysis is run, and the results show that all the variables selected to have a perfect positive linear relationship. The regression equation for freight transport mode is given below.

$$\hat{Y_f} = -713.32 + 1,914.21 x_{ENERGY} - 676.54 x_{GHG} + e_i \tag{3}$$

The Y intercepts, computed as -713.32, estimates the expected performance in TKM that was fulfilled in 2005 when the average energy demand per (ktoe) is zero, given no green house gas emissions have occurred. The slope of average energy demand with TKM, (b_1, computed as 1,914.21) means that for each unit of GHG emitted, the expected performance in TKM is estimated to increase to 1,914.21 (ktoe) p.a for one-unit increase in energy demand. The slope of GHG with TKM (b_2, computed as -676.54) means that, in a given year with a given average energy demand, the expected performance in TKM is estimated to decrease by 676.54 TKM for each additional ktoe of GHG emitted.

The regression equation for passenger transport mode is given below.

$$\hat{Y_p} = 150.66 + 12.51 x_{ENERGY} - 0.81 x_{GHG} + e_i \tag{4}$$

The Y intercepts, computed as 150.66, estimates the expected performance in PKM that was fulfilled in 2005, when the average energy demand per (ktoe) is zero given no GHG discharge has occurred. The slope of average energy demand with PKM (b_1, computed as 12.51) means that for each unit of GHG emitted, the expected PKM is estimated to increase by 12.51 p.a for one-unit of ktoe increase in energy demand. The slope of GHG with PKM (b_2, computed as -0.81) means that in a given year with a given average energy demand, the expected performance in PKM is estimated to decrease by 0.81 for each additional ktoe of GHG discharge. In order to compute efficiency scores, DEA Solver Pro 5.0 is used. DEA results obtained from (1) tell us that in the past i.e. 2005, energy demanded and GHG emitted were inefficiently managed, while in 2009, there was efficient utilization under CRS assumption (about 4.76% of the total). However, if the rate of consumption is maintained up to 2025, energy demanded will be efficiently utilized under VRS and BaU scenario.

Those inefficient years are listed in Table 5 with their energy, and GHG excesses and output shortfalls. The period 2010-2024 appears to be inefficient years under both CRS

Table 5: Sources of Inefficiency in Overall Performance

		Input excesses		Output deficits	
S/No.	DMU	Energy	GHG	TKM	PKM
1	2005	109.83(310.11)	244.35	–	119.36
2	2006	–	239.29	391.76	117.83
3	2007	–	233.69	389.85	116.03
4	2008	–	227.54	386.75	113.84
5	2009	–	220.71	382.35	111.32
6	2010	–	213.37	376.52	108.44
7	2011	–	205.31	369.15	105.15
8	2012	–	196.54	360.07	101.47
9	2013	–	187.04	349.16	97.36
10	2014	–	176.77	336.21	92.71
11	2015	–	165.69	321.08	87.53
12	2016	–	153.73	303.55	81.93
13	2017	–	140.89	283.45	75.69
14	2018	–	127.12	260.56	68.76
15	2019	–	112.33	234.61	61.32
16	2020	–	96.52	205.39	53.11
17	2021	–	79.61	172.62	44.13
18	2022	–	61.56	136.00	34.43
19	2023	–	42.34	95.25	23.76
20	2024	–	21.82	50.02	12.39

Figures in parenthesis is representing freight transport

and VRS, assumptions BaU scenario, even though there was a gradual improvement in efficient utilization and discharges of carbon dioxide see Figure 1. After that period, 2025 becomes an efficient year under both CRS and VRS assumptions. The deficits/excesses column provides some additional information about the efficient utilization of energy and

GHG discharged in 2005, as compared to the succeeding years. Specifically, the following years have at least as much of each output as compared to the year 2005, and provides 119.36 more PKM (surplus). The excess energy and GHG excess columns tells us that

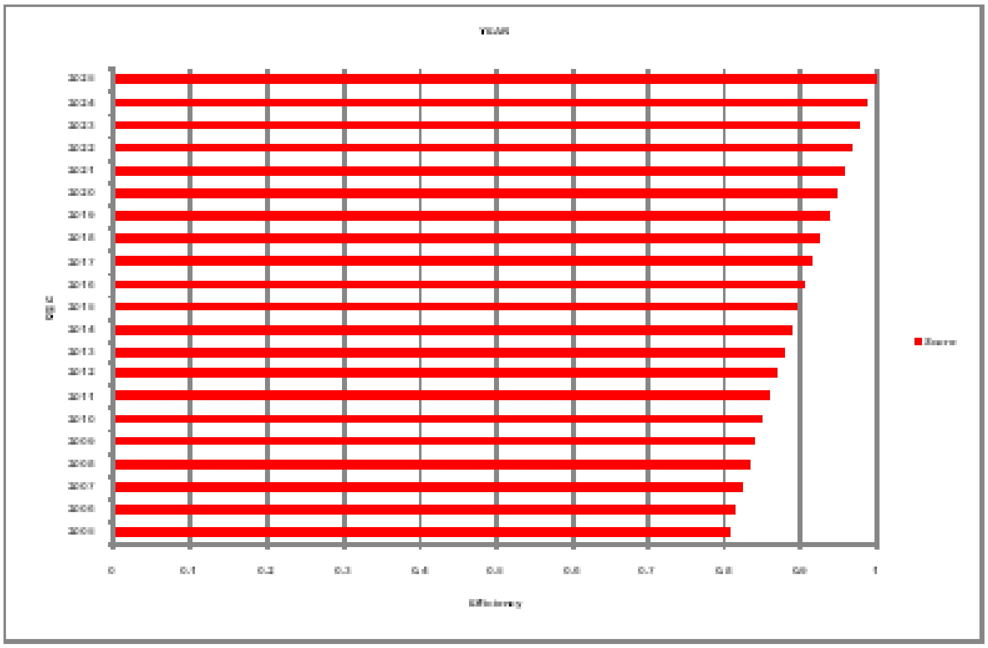

Figure 2: Transport Sector Performance From 2005 to 2025 Before Countermeasure

Figure 2 shows the level of efficiency scores attained in various years from the least up to the maximum, for example, in the year 2005. The efficiency score is 80.8%, this will gradually increase up to 100% in the year 2025 under CRS and BaU assumptions. The optimum efficiencies are shown in Table 6. We first note that the values of the objective functions show the efficiencies scores for subsequent years before and after countermeasure was taken and listed as TKM and PKM in billion of a kilometer. For example, the efficiency score for the year 2005 before the countermeasure is 80.8% for freight and 85.3% for passenger transport respectively. These scores mean that in the year 2025, we can obtain at least the level of each output that was achieved in 2005, by having available, no more than 80.8% and 85.3% of the energy consumed, and GHG emitted in 2005. Thus, the succeeding year 2025 will be more efficient, and the DEA analysis identified energy consumption in the year 2005 as being relatively inefficient under CRS assumption, although it is efficient under VRS. Table 6 also gives information about peer(s) for the years considered inefficient in the analysis. Peers are efficient DMU (years) with a performance score of 100% and all slack zero. For instance, 2005 peer is 2025, meaning that DMU(2005) can try to emulate the

Table 6: Efficiency Scores and Peer Group Before and After Counter Measure

		BEFORE				AFTER			
S/No.	DMU	TKM	Peer	PKM	Peer	TKM	Peer	PKM	Peer
1	2005	80.8	2025	85.3	2025	39.4	2025	38.2	2025
2	2006	81.7	2025	85.9	2025	41.2	2025	40.0	2025
3	2007	82.5	2025	86.6	2025	43.2	2025	41.9	2025
4	2008	83.4	2025	87.2	2025	45.2	2025	44.0	2025
5	2009	83.3	2025	87.9	2025	47.3	2025	46.1	2025
6	2010	84.2	2025	88.6	2025	49.5	2025	48.3	2025
7	2011	85.1	2025	89.3	2025	51.8	2025	50.7	2025
8	2012	86.1	2025	90.0	2025	54.3	2025	53.2	2025
9	2013	87.0	2025	90.7	2025	56.9	2025	55.8	2025
10	2014	88.9	2025	91.4	2025	59.6	2025	58.5	2025
11	2015	89.9	2025	92.1	2025	62.4	2025	61.4	2025
12	2016	90.9	2025	92.9	2025	65.4	2025	64.4	2025
13	2017	91.8	2025	93.6	2025	68.5	2025	67.6	2025
14	2018	92.8	2025	94.4	2025	71.8	2025	71.0	2025
15	2019	93.8	2025	95.2	2025	75.2	2025	74.5	2025
16	2020	94.8	2025	95.9	2025	78.9	2025	78.2	2025
17	2021	95.8	2025	96.7	2025	82.7	2025	82.1	2025
18	2022	96.9	2025	97.5	2025	86.7	2025	86.3	2025
19	2023	97.9	2025	98.3	2025	90.9	2025	90.6	2025
20	2024	98.9	2025	99.2	2025	95.3	2025	95.2	2025
21	2025	1.0	–	1.0	–	1.0	–	1.0	–

DMU (2025) by achieving better values of inputs that would result in the efficiency score of 100%. Clearly, the succeeding year (2025) is more efficient than a preceding year (2005), and we are justified in concluding that the year 2005 is relatively inefficient compared to the consecutive years in one successive series. Figure 3 describes the level of efficiency scores attained in various years, from the least up to the maximum, for example, in the year 2005 the efficiency score is 39.4%. This gradually increases to 100% in the year 2025 under CRS and BaU assumptions.

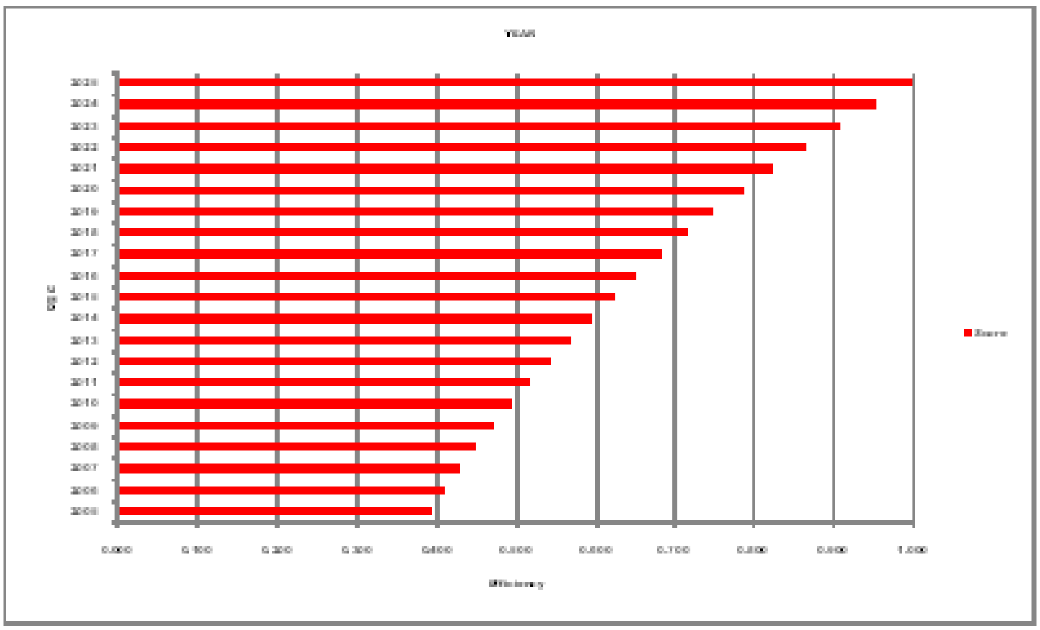

Figure 3: Transport sector performance from 2005 to 2025 after countermeasure

5 Policy Implication

The analyses of the existing IM growth pattern, their projections and countermeasures, have a number of policy implications. During 2005-2009, freight transport performance (TKM) has grown up to 5.62% p.a, while passenger transport performance(PKM) has grown at about 3.99% p.a [2, 12]. Therefore, the current transportation growth is very rapid, and these trends are unsustainable in the future. Regression analysis estimates has shown that a point to a growth of about 5.43% for TKM and 3.80% p.a for PKM until the year 2024-2025. Public transportation systems provide the minimum energy consumption; GHG emissions, and cost per TKM or PKM. For instance, electric traction of railways consumes about 0.11MJ, and buses consume 0.212 MJ per PKM, which are much lower than the corresponding values for gasoline vehicles [14, 15]. Modal share in their favor can significantly reduce the energy demand and GHG emission. They also decrease the amount of excessive traffic bottlenecks in the cities. For instance, buses accomplish 88% of the passenger journey in Iskandar's city, while they form only 12.6% of the share of the total passenger car equivalents.

Consequently, the usage of public transport should be encouraged wherever possible. Initially, the important requirement is to increase the speed, comfort, and reliability of mass transit. The use of personal motor cars should be discouraged by road pricing, and discourage parking of personalized motor vehicles. The parking space in cities, especially in overcrowded areas, should be made very limited, and charges should be levied. Raising the cost price of cars and subsidizing mass transit fare will discourage car ownership and compel people to use public transport. Government should deregulate the transport sector to allow private participation. Railways have the environmentally none threatening defining features; low energy consumption and low GHG emission per TKM and PKM. Therefore, investment in railways has many advantages, for example railways have also been shown to contribute to social quality and economic competitiveness in its ability to transport large amounts of goods and people to city centers and inner suburbs. Low GHG emissions can avoid adverse climate change.

6 Conclusion

In this analysis, the overall performance of the IM transport sector for the past five years was evaluated. It has been shown that both the freight and passenger traffic have witnessed a high growth rate (about 5.62% and 3.99% p.a, respectively) during the period 2005 to 2009. Expansion in road transport and the number of road transport vehicles have been identified to be responsible for such a huge increase. It has been shown that the growth of the different sectors of transport is beset with inadequate infra structural facilities. The rectification of these inadequacies would require massive capital investments. Rail transport has fared well in terms of energy demand and carbon dioxide emissions. Forecasts of freight and passenger traffic up to the year 2025 using annual growth rate and multiple linear regression approach have pointed to a rapid rise in transport demands (about 5.43% for freight, and 3.80% for passenger traffic) during 2005 to 2009. Subsequent regression analysis has shown that the forecasts of traffic are likely to increase the energy demand and GHG emissions by more than 4.1 times in 2025 compared to the 2005 levels.

Consequently, certain alternative policy counter measures could reduce them considerably (as noted in Figure 3). Efficiency improvement has reduced the forecasts by 23% compared to the BaU scenario. While, expected diffusion of substitute fuel vehicles (bio fuel and natural gas) has been found to cause large, changes in modal share in favor of mass transit, rail has been shown to have the potential to reduce the BaU projections by more than 39%. In all, from this study, there is a need for substituting personal vehicles' transport with mass transit and (rail) trains. To improve transport demand management, efficiency of the vehicles and fuel type should be shifted from oil to natural gas and bio fuel because of the environmentally benign characteristics. Therefore, the DEA approach can be used to monitor, plan and improve the productivity of IM's transport sector. Given the results of the DEA analysis as obtained in this paper and as part of the mitigating measures, the management of IM's transport sector should examine the existing operations with a view of determining how energy is consumed. This will help in evolving important policy options towards sustainable low-carbon IM by 2025.

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