# A DEA ANALYSIS OF ENERGY CONSUMPTION IN TRANSPORT SECTOR AND CARBON DIOXIDE EMISSIONS IN SELECTED 85 COUNTRIES OF THE WORLD

by Asif Ahmed**, Akimasa Fujiwara***, and Juni Zhang****

Abstract

This study attempts to apply Data Envelopment Analysis (DEA) to evaluate environmental efficiency in transport sector for the selected 85 countries of the world. Selected countries are chosen from Developed, Industrialized, Transition and Developing countries. Four indicators focusing on energy consumption and carbon dioxide emissions for the year 2004 are employed in the analysis. The analysis shows that Belgium, Iceland, Japan, Argentina, India, Singapore, Belarus, Turkey, United Kingdom and Bangladesh are considered efficient, and Luxembourg, Iran, Czech Republic and Uzbekistan are rated as the least efficient under constant returns to scale (CRS) assumption for the four groups of countries. The patterns of changes in efficiency of the countries are further analyzed using Malmquist Productivity Index (MPI) approach for the period of 1992–2004. The analysis shows that there is progress in achieving higher values of output-side indicators and in achieving lower values of the input-side indicators in the year 2004 compared to 1992 for 33 out of the 85 countries.

## 1. Introduction

Global emissions of Green House Gasses (GHGs) rose 70% from 1970 to 2004- or roughly 1.6% per year and $CO_2$ emissions largely dominate and have risen 80% between 1970 and 2004 (1.9% /yr).Of the estimated 49 Gt of GHGs emitted globally in 2004, approximately 56.6% resulted from the combustion of fossil fuel. Transport sector was responsible for 23% of world $CO_2$ emissions from the fuel combustion (30% for OECD countries) with the road sector largely dominating. When factoring in all GHG emissions, transport $CO_2$ emissions accounted for approximately 13% of global GHG emissions[1)].

Patterns in the level of energy consumption, economic activity and $CO_2$ emissions of many countries or regions of the world have been analyzed in the literature. Mielnik and Goldemberg [2)] have studied carbon emission intensities of a group of developing countries. Long term patterns in sector-wise $CO_2$ emissions from energy use in OECD countries is studied by Schipper et al.[3)] using factorial analysis and using Laspeyres index. Ringuis et al.[4)] have used indicators such as $CO_2$ emissions per GDP, GDP per capita, and $CO_2$ emission per capita to identify the effect of burden sharing on different OECD countries using multi-criteria analysis. Ramanathan[5)] has studied the carbon emissions of many countries of the world using several indicators. Fujiwara et al.[6)] employed DEA to evaluate environmental efficiency in transport sector in different cities of the world. However, a survey of the literature points to the absence of any substantial analysis of energy consumption and carbon dioxide emissions in the transport sector of the countries around the world. This paper attempts to provide such an analysis using Data Envelopment Analysis and Malmquist Productivity Index approach.

## 2. Methodology: DEA and MPI approach

Data Envelopment Analysis (DEA) is a methodology based upon an interesting application of linear programming. It has been successfully employed for assessing the relative performance of a set of firms, usually called Decision-Making Units (DMU), which use a variety of identical inputs to produce a variety of identical outputs. The basic ideas behind DEA date back to Farrel[7)], but the recent series of discussions started with the article by Charnes et al.[8)]. The basic formulation of DEA is given below

$$\max \frac{\sum_{j=1}^{J} v_{jm} y_{jn}}{\sum_{i=1}^{I} u_{im} x_{im}} \quad \textit{Subject to} \quad 0 \le \frac{\sum_{j=1}^{J} v_{jm} y_{jn}}{\sum_{i=1}^{I} u_{im} x_{in}} \le 1;\ \mathrm{n} = 1,2, \ldots\ldots, \mathrm{N} \qquad (1)$$

$$v_{jm}, u_{im} \ge \varepsilon;\ i = 1,2,\ldots, I;\ j = 1,2,\ldots, J$$

*Keyword: *Data Envelopment Analysis (DEA), Malmquist Productivity Index (MPI), Energy Consumption, Road Transport Sector*

** M.Eng. Student of IDEC, Hiroshima University
(Room # IDEC301, 1-5-1 Kagamiyama, Higashi-Hiroshima 739-8529, Japan, Email: asifahmed75@yahoo.com )
*** Member of JSCE, Dr. Eng., Faculty of IDEC, Hiroshima University
(Room # IDEC409, 1-5-1 Kagamiyama, Higashi-Hiroshima 739-8529, Japan, TEL+FAX: 81-82-424-6921 Email: afujiw@hiroshima-u.ac.jp )
*** Member of JSCE, Dr. Eng., Faculty of IDEC, Hiroshima University
(Room # IDEC410, 1-5-1 Kagamiyama, Higashi-Hiroshima 739-8529, Japan, TEL+FAX: 81-82-424-6919 Email: zjy@hiroshima-u.ac.jp )

where the subscript i stands for inputs, j stands for outputs and n stands for the DMUs. The optimal value of the objective function of Model 1 is the DEA efficiency score assigned to the mth DMU. If the efficiency score is 1 (or 100%), the mth DMU satisfies the necessary condition to be DEA efficient; otherwise, it is DEA inefficient. Note that the inefficiency is relative to the performance of other DMUs under consideration.

The output based Malmquist Productivity Index [9)] is defined as follows

$$M^{t+1}\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \left[\frac{D^t\left(x^{t+1}, y^{t+1}\right)}{D^t\left(x^t, y^t\right)} \frac{D^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D^{t+1}\left(x^t, y^t\right)}\right]^{1/2} \tag{2}$$

where $D^t$ is a *distance function* measuring the efficiency of conversion of inputs $x^t$ to outputs $y^t$ in the period t. DEA efficiencies have been considered as a distance measure as it reflects the efficiency of conversion of inputs to outputs. Technical efficiency change (E) measures the change in the CRS technical efficiency of Period t+1 over the Period t. If E>1, then there is an increase in the technical efficiency of converting inputs to outputs. T represents the average technological change over the two periods[10)] .

3. Data and Tools

The indicators considered in the analysis are: $CO_2$ emissions from the transport sector per capita (denoted as $CO_2$ per cap hereafter), total energy consumption by the transport sector (Energy), gross domestic product per capita (GDP per cap) and percentage of urban people to total population (Urbanization). Of the four, $CO_2$ and Energy are minimization indicators in the sense that countries that register the lowest values in these indicators are more preferred. Hence, these indicators are considered as the input-side indicators of the DEA program, as they have the characteristics of the inputs in DEA. Similarly, the indicators GDP and Urbanization are considered as output-side indicators of the DEA program. The time series data for the period of 1992 -2004 have been obtained from the International Energy Agency database. All 85 countries are subdivided into four groups namely developed countries, industrialized countries, transition countries and developing countries. The DEA analysis in this study has been performed using the DEAP (Data Envelopment Analysis Program) software package[11)].

4. Results and Analysis

Table 1 shows the DEA result for the year 2004 and Malmquist Productivity Index (MPI) during 1992 – 2004 for each country. It is revealed that 10 out of the 85 countries have been considered efficient (in terms of the energy consumption and carbon emission indicators considered in the analysis) under the CRS assumption in 2004. They are Belgium, Iceland, Japan, Belarus, Turkey, United Kingdom, Argentina, India, Singapore and Bangladesh. These countries have been considered in this study as producing more outputs (GDP and Urbanization) with less energy consumption and carbon emissions from the transport sector compared to the remaining 85 countries considered in the analysis during 2004. When VRS is assumed, other 11 countries namely Denmark, Luxembourg, Netherlands, Norway, Portugal, Brazil, Philippines, Chili, Israel, Ghana and Kuwait have also been considered efficient.

As expected, the VRS efficiencies that measure pure technical efficiencies excluding effects of scale of operations are larger than the corresponding CRS efficiencies. For example, the CRS efficiency of Australia is 0.627, and its score increases to 0.911 under the VRS assumption. The CRS efficiency score is lower because this country does not operate at a best possible scale size. The ratio of CRS and VRS efficiency is the scale efficiency. For example, the scale efficiency of Australia is 0.688 (<1), meaning that the country is not able to register unit efficiency because it is not operating at the most productive scale size, and its present size of operations reduces its pure technical efficiency (i.e. the VRS efficiency) by 31.2%.

The patterns of changes in efficiency of the countries are further analyzed using Malmquist Productivity Index (MPI) approach for the period of 1992–2004. First of all, the results of DEA analysis of performance of the countries in an earlier year, namely 1992, were calculated. There are some interesting changes in the efficiencies of all these countries in the year 1992 compared to 1996. For example, in the case of developed countries, Belgium, Japan and Spain are considered efficient during 1992 but in 2004 changed to Belgium, Japan and Iceland. While Luxembourg registered the least CRS efficiency in 1992 (also in 2004), the least VRS efficiency is recorded by Greece and Germany (Greece and Ireland in 2004). The geometric mean of the CRS efficiencies of all the developed, transition and developing countries is lower (0.771, 0.578, 0.307 respectively) in the year 1992 compared to the mean value registered in 2004 (0.781, 0.593 & 0.314). In case of industrialized countries, the geometric mean of the CRS efficiencies is higher (0.733) in the year 1992 compared to the mean value registered in 2004 (0.653).

The MPI and other indices for the 12 year period of 1992–2004 are also calculated in this study. The values reported in the MPI column of table1 are the geometric means of the indices recorded for the one-year periods 1992–1993, 1993–1994, 1994–1995 to 2003–2004. The MPI for Australia is 0.996, indicating there is a decrease in achieving higher values of GDP and urbanization and in achieving lower values of energy consumption and carbon emissions from the transport sector for this country in the year 2004 compared to 1992. The decrement of MPI is contributed by a reduction in technology change (0.988) and an increase in technical efficiency change (1.008). But an achievement in MPI is obtained for Germany (1.003) during the time period of 1992-2004. Thus, the analysis shows that the increase in MPI for Germany during the period is contributed by better technical efficiency rather than technology improvements. Please note that, the term 'technology' is traditionally used in DEA/MPI analyses where performance of a set of production firms is compared. When the same concept is extended to comparing the performance of nations, the term 'technology' should be considered a generic term referring to technological practices and social institutions of a country that help produce more GDP and urbanization with less energy consumption and carbon emissions from transport sector in a country. This means that, during the period of 1992–2004, there have been more changes in efficiency improvement practices in Germany that just changes in the technology of operations.

Table 1: Relative efficiencies in 2004 and efficiency changes over the period 1992-2004.

| Developed Countries[1] | | | | Industrialized Countries[2] | | | | Transition Countries[3] | | | | Developing Countries [4] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COUNTRY | CRS | VRS | MPI | COUNTRY | CRS | VRS | MPI | COUNTRY | CRS | VRS | MPI | COUNTRY | CRS | VRS | MPI |
| Australia | 0.627 | 0.911 | 0.996 | **Belarus** | 1 | 1 | 1.08 | Algeria | 0.565 | 0.875 | 1.006 | Azerbaijan | 0.136 | 0.66 | 0.992 |
| Austria | 0.718 | 0.784 | 0.974 | Bulgaria | 0.59 | 0.933 | 0.949 | **Argentina** | 1 | 1 | 1 | **Bangladesh** | 1 | 1 | 0.99 |
| **Belgium** | 1 | 1 | 0.988 | Croatia | 0.533 | 0.73 | 0.967 | Brazil | 0.643 | 1 | 0.992 | Bolivia | 0.192 | 0.831 | 0.995 |
| Canada | 0.485 | 0.852 | 0.997 | Czech Rep. | 0.452 | 0.894 | 0.953 | China | 0.906 | 0.97 | **1.005** | Chile | 0.367 | 1 | **1.008** |
| Denmark | 0.974 | 1 | 0.993 | Estonia | 0.528 | 0.881 | 0.976 | Egypt | 0.529 | 0.652 | 0.984 | Colombia | 0.311 | 0.938 | **1.015** |
| Finland | 0.71 | 0.764 | 0.995 | Hungary | 0.632 | 0.86 | 0.984 | **India** | 1 | 1 | **1.021** | Costa Rica | 0.324 | 0.72 | **1.006** |
| France | 0.94 | 0.966 | 0.996 | Latvia | 0.527 | 0.878 | **1.013** | Indonesia | 0.435 | 0.739 | 0.974 | Dominican R | 0.285 | 0.821 | 0.994 |
| Germany | 0.762 | 0.873 | **1.003** | Lithunia | 0.556 | 0.869 | **1.007** | Iran | 0.216 | 0.719 | 0.971 | Ecuador | 0.121 | 0.747 | 0.988 |
| Greece | 0.666 | 0.754 | **1.003** | Poland | 0.739 | 0.836 | 0.989 | Kazakhstan | 0.417 | 0.746 | **1.061** | Ghana | 0.503 | 1 | 0.967 |
| **Iceland** | 1 | 1 | **1.002** | Romania | 0.69 | 0.758 | 0.985 | Malaysia | 0.348 | 0.71 | 0.983 | Guatemala | 0.333 | 0.628 | 0.965 |
| Ireland | 0.59 | 0.754 | 0.964 | Russian Fed. | 0.377 | 0.892 | **1.003** | Mexico | 0.645 | 0.826 | **1.003** | Israel | 0.788 | 1 | **1.011** |
| Italy | 0.921 | 0.972 | 0.99 | Slovakia | 0.508 | 0.729 | 0.976 | Pakistan | 0.587 | 0.799 | 0.981 | Jordan | 0.153 | 0.93 | **1.001** |
| **Japan** | 1 | 1 | 0.997 | Slovenia | 0.562 | 0.591 | 0.994 | Philippines | 0.636 | 1 | 0.932 | Kenya | 0.241 | 0.469 | **1.005** |
| Luxembourg | 0.165 | 1 | 0.969 | **Turkey** | 1 | 1 | **1.001** | Saudi Arabia | 0.382 | 0.815 | 0.993 | Kuwait | 0.375 | 1 | **1.01** |
| Netherlands | 0.984 | 1 | 0.998 | Ukraine | 0.762 | 0.925 | **1.013** | **Singapore** | 1 | 1 | **1.031** | Lebanon | 0.368 | 0.992 | **1.026** |
| New Zealand | 0.642 | 0.885 | 0.977 | **U K** | 1 | 1 | **1.018** | South Africa | 0.493 | 0.673 | **1.001** | Libya | 0.268 | 0.83 | 0.965 |
| Norway | 0.787 | 1 | 0.997 | | | | | South Korea | 0.851 | 0.888 | **1.002** | Nigeria | 0.291 | 0.663 | **1.023** |
| Portugal | 0.831 | 1 | 0.971 | | | | | Thailand | 0.334 | 0.372 | 0.989 | Oman | 0.436 | 0.794 | 0.992 |
| Spain | 0.87 | 0.888 | 0.974 | | | | | UAE | 0.407 | 0.932 | **1.016** | Paraguay | 0.178 | 0.73 | 0.969 |
| Sweden | 0.94 | 0.975 | 0.998 | | | | | Venezuela | 0.46 | 0.992 | 0.989 | Peru | 0.391 | 0.928 | **1.004** |
| Switzerland | 0.943 | 0.967 | **1.004** | | | | | | | | | Sri Lanka | 0.203 | 0.301 | 0.974 |
| United States | 0.406 | 0.957 | 0.998 | | | | | | | | | Sudan | 0.374 | 0.777 | **1.021** |
| | | | | | | | | | | | | Syria | 0.115 | 0.648 | **1.03** |
| | | | | | | | | | | | | Tunisia | 0.339 | 0.835 | 1 |
| | | | | | | | | | | | | Uzbekistan | 0.101 | 0.473 | 0.976 |
| | | | | | | | | | | | | Viet Nam | 0.146 | 0.371 | 0.933 |
| | | | | | | | | | | | | Yemen | 0.137 | 0.38 | **1.044** |

It is depicted from the above table that there is progress in achieving higher values of output-side indicators and in achieving lower values of the input-side indicators in the year 2004 compared to 1992 for 33 out of the 85 countries. Of these 33 countries, more achievement has been obtained is developing countries (48% countries) and least in developed countries (18% countries). The best performing country for these 12years period is Belarus (MPI=1.08) and the worst is registered to Philippines (MPI=0.932). Analysis shows that developed countries and transition countries (except Singapore and UAE) achieved progress due to efficiency improvement rather than technology change and industrialized nations achieved progress due to technology improvement rather than efficiency change. On the contrary, for developing nations there is not a single country in this group who achieve this progress due to technology change.

5. Policy implications of the study

A remarkable observation of the study is that most of the countries (52 out of 85, 61.18%) are not considered as efficient, and hence are not considered to be following carbon friendly energy practices for their transport sector. This is

---

[1] Developed Countries are those countries which qualify all these 7 criteria namely: CIA's The World Fact book, Developed countries, international Monetary Fund, Advanced economies, Human Development Index at or above 0.9, CIA's The World Fact book, Advanced economies, World Bank, High-income economies, Quality-of-life index at or above 7.0 and High-income OECD members.

[2] Industrialized Countries are those countries as Annex I parties defined by the Kyoto Protocol subtracted by the Developed Countries listed in Table 1. Note that Liechtenstein and Monaco has not been considered due to lack of data.

[3] Transition Countries are selected from the Newly Industrialized Country, Four Asian Tigers, G 20, Emerging Market, Next 11 economic countries, G 20 economic important countries and Developing Countries but listed within the top ranked 30 $CO_2$ emitting countries. Note that Turkey and Russia are deducted as they are considered as industrialized country. Taiwan and Hong Kong are not considered due to lack of consistent data. Though Bangladesh was listed in Next 11 countries it has been considered in the developing country list in table 1.

[4] Developing countries are chosen on the basis of top ranked 30 $CO_2$ emitter countries from transport sector during 2004. Note that Iraq, Myanmar and Qatar have not been considered due to lack of consistent data.

may be due to the fact of high dependability of road transport share in compare with other transport mode. Road transport uses mainly fossil fuel which is potential source of $CO_2$ emissions. During 2005 transport sector registers 23% of world $CO_2$ emission from fuel consumption where road transport's share is 17.1 %[1]. Total energy consumption for these 85 countries increase from 1466 MTOE (Million Ton Oil Equivalent) to 1910 MTOE during the last 12 years and average energy consumption rate for road transport is (2.8% per year) higher than total transport (2.5% per year). Another important observation has been found from figure 1 that energy consumption in road sector remain more or less constant for this period and the average value is registered as 78.88% of total transport sector. These dependencies for developing countries are higher (85.16 %) and lower for industrialized countries (60.67 %). This is truly reflected on DEA study that mean CRS efficiency for industrialized nation (0.653) is much higher than that of developing countries (0.314). So policies focusing on road sector transport are needed to address carbon friendly transport sector development.

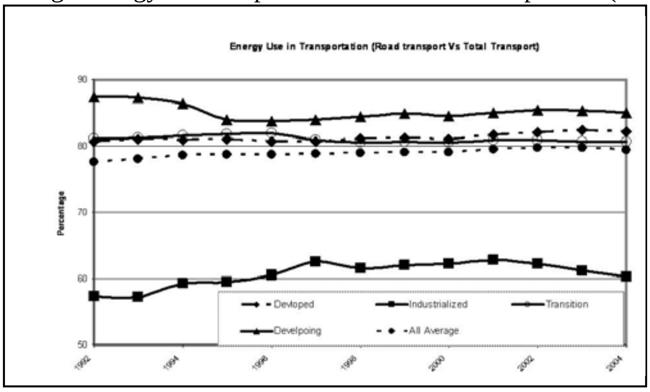


Figure 1: Percent of Energy Consumption in Total Transport to Road Transport Sector for 85 countries in 1992 to 2004.

## 6. Summary

Performances of selected 85 countries of the world in terms of four indicators of energy consumption and $CO_2$ emission from transport sector have been studied in this paper using Data Envelopment Analysis. The analysis ranked the countries on the basis of a relative efficiency score obtained by combining the indicators and specified peers (efficient countries) for inefficient countries whom they can emulate for becoming efficient. General conclusion has been drawn from the analysis is that most of the countries are inefficient as large share of road transport to total transport which uses carbon intensive fossil fuel. During 2004, 10 countries are found to be efficient under CRS assumption. The patterns of efficiency change of the countries over the period of 1992–1996 have been further analyzed using the Malmquist Productivity Index approach. The analysis has shown that there has been a progress in achieving higher values of output-side indicators and in achieving lower values of the input-side indicators in the year 2004 compared to 1992 for 33 countries (Developed -4, Industrialized -7, Transition -9 & Developing -13). A general policy conclusion on the basis of the study is that most of the developing countries (mean efficiency value registered for 2004 is 0.314) considered in the study do not seem to follow carbon-friendly transport policies for their economic development.

The analysis presented in the study could be extended further and improved by considering more number of countries, fine tuning dividing into groups and more time periods. It might also be interesting to extend the model to include for transport related parameter such as modal share of private and public transport, transport network accessibility index, car ownership, fuel efficiency index etc. These form directions for future research.

References


1) Greenhouse Gas Reduction Strategies in the Transport Sector: Preliminary Report, OECD/ITF, 2008.
2) Mielnik O, Goldemberg J, The evolution of the carbonization index in developing countries. Energy Policy 1999; 27(5): 307–8.
3) Schipper L, Ting M, Khrushch M, Golove W. The evolution of carbon dioxide emissions from energy use in industrialized countries: an end-use analysis. Energy Policy 1997; 25(7–9):651–72.
4) Ringuis L, Torvanger A, Holtsmark B. Can multi-criteria rules fairly distribute climate burdens? OECD results from three burden sharing rules. Energy Policy 1998; 26(10):777–93.
5) Ramanathan R. Combining indicators of energy consumption and CO2 emissions: a cross-country comparison. Int J Global Energy Issues 2002; 17(3):214–27.
6) Akimasa Fujiwara, Junyi Zhang and Daisuke Yoshino. An evaluation of environmental efficiency in transport system; presented paper on conference of Sustainable Transport for Developing Countries, 28-29 August, 2008, Dhaka Bangladesh.
7) Farrel MJ., The measurement of productive efficiency. J Royal Stat Soc (A) 1957; 120:253–81.
8) Charnes A, Cooper WW, Rhodes E., Measuring efficiency of decision making units. European Journals of Operational Research 1978; 2:429–44.
9) Malmquist S. Index numbers and indifference surfaces, Trabajos de Estatistica 1953; 4:209–42.
10) Ramanathan R. An introduction to data envelopment analysis. New Delhi: Sage; 2003.
11) Coelli T. A guide to DEAP version 2.1: a data envelopment analysis (computer) program, CEPA working paper 96/08. Australia: Centre for Efficiency and Productivity Analysis, University of New England; 1996.