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ENERGY INTENSITY AND CARBON FACTOR IN CO_2 EMISSION INTENSITY

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ABSTRACT

In the evolution of carbon dioxide emission intensity, the role of energy intensity or carbonization index is mainly an empirical issue that cannot be resolved with certainty from the experience of a group of countries during a given period of time. The present empirical study reveals that CO_2 emission intensity cannot be evaluated unambiguously using either variation in carbon emission factor or energy intensity as the criterion. Different levels of CO_2 emission intensities in different regions result from different causes. These include large variation in explanatory factors in the data, the measure of economic output, and structural comparability.

1. INTRODUCTION

Energy related carbon dioxide (CO_2) emissions are expected to increase substantially due to rapid growth in the use of energy. The CO_2 emission intensity, given by the ratio of CO_2 emission (C) to GDP (G), is an indicator that shows how intensive carbon dioxide is in an economy. It is an important index in current energy statistical systems [1]. It is generally accepted that lower CO_2 emission intensity indicates better environmental quality. At the aggregate level, the level of energy-related CO_2 emission intensity of a country could be expressed as the product of the aggregate carbon factor (ratio of carbon dioxide and energy) and the aggregate energy intensity (ratio of energy and GDP). The aggregate carbon factor, which is also referred to as the "carbonization index," gives the average

CO_2 emission due to per unit use of energy. Its value primarily depends on the fuel mix and the carbon emission factor.[1] It evaluates fuel quality, fuel switching, and adoption of abatement technologies. On the other hand, the energy intensity in an economy indicates the average energy requirement to produce one unit of economic output in monetary terms. This energy intensity is primarily affected by the pattern of economic development, the structure of the economy, country size, population density, life style, fuel type, energy endowment, and the efficiencies with which energy sources are used. Energy intensity in particular is dependent on factors that can be influenced by policy options [2].

Some previous studies have examined empirically the factors that affect the emissions of CO_2 in a specified country or group of countries. Examples of such studies for the OECD countries include Greening and colleagues [3], Sun and Malaska [4], and Viguier [5]. Studies on the developing countries can be found in Ang and colleagues [6] and Han and Chatterjee [7]. Cross-country/region comparisons of CO_2 emissions are reported in Ang and Zhang [8] and Chung [9]. The main findings in most of these studies indicate that the contribution of the carbon factor is marginal as compared to the energy intensity in accounting for the differences in CO_2 emissions.

Mielnik and Goldemberg [10] have indicated that in assessing the pattern of contribution of industrialized and developing countries in climate change the "carbonization index" is a useful indicator. Using a graphical presentation on time scale (from 1971 to 1994), they indicate that the industrialized countries are "decarbonizing" significantly while the developing countries are "carbonizing" mainly due to activities in Asian-Pacific region (particularly China and India) and Africa. Ang [2], however, insists on the greater importance of energy intensity in the context of 10 large disaggregated regions of the world. In support of his stand, he estimates the coefficient of variation (CV), given by the standard deviation as a percentage of the mean, for the year 1995. He also indicates that the percentage change in energy intensity is higher than the carbon factor for the period from 1971 to 1995.

The primary focus of the present study is to reevaluate the relationship between CO_2 emission intensity and energy intensity or carbon factor. However, unlike the above two studies, the objective of this article is to identify the extent of carbon factor and energy intensity in influencing the changes in CO_2 emission intensity. This analysis is based on a time scale and geographical regions different from those considered by Mielnik and Goldemberg [10], and Ang [2]. Following a bivariate regression technique and complete decomposition model, the present study attempts to determine the relative role of the factors which influence the

[1] For a specified type of fuel, the carbon emission factor does not vary significantly over time or across countries. Low-quality energy sources emit a high rate of CO_2 and vice versa. Different sources of energy imply different carbon factors.

changes in CO_2 emission intensity in four groups of countries—OECD countries, Asian countries, non-OECD European countries, and Latin American countries.

The study is organized as follows. In section 2, the models to be used and estimated are specified. In section 3, the sources and specification of the data are reported. The estimated models and empirical results are reported and analyzed in section 4. Conclusions are presented in the final section.

2. MODELS

As stated above, the primary focus of the present study is to evaluate the relationship between carbon dioxide emission intensity and energy intensity or carbon factor (carbonization index). Ignoring the direct influence of GDP, the level of CO_2 emission intensity in a country is considered to be a function of the carbon factor and energy intensity. In this article, our analysis is based on a regression technique and the complete decomposition model, proposed by Sun [1]. In a complete decomposition model, the difference in CO_2 emission intensity among countries is assumed to depend on two explanatory factors—namely the CO_2 emission factor and energy intensity. First we apply a bivariate regression technique of the following form:

$$X_i = \alpha_1 + \beta_1 Y_i + \varepsilon_{i1}$$

$$X_i = \alpha_2 + \beta_2 Z_i + \varepsilon_{i2}$$

where X is the carbon dioxide emission intensity, Y is the carbon factor, and Z is the energy intensity.

We then apply a decomposition technique to determine the relative contribution of the factors, particularly, energy intensity and carbon factor, that change the CO_2 emission intensity. A review of decomposition methodology in energy studies can be found in Ang [11]. Recently Sun [1] has applied a complete decomposition method that Zhang and Ang [12] refer to as the Refined Laspeyres Method (RLM). The purpose of proposing the complete decomposition model is to improve the reliability and accuracy of the general decomposition model [1]. The residual/interaction term in the complete decomposition method is allocated to the factors jointly created and equally distributed, proposed by Sun [1].

Assume that a variable X is determined by two factors Y and Z, and X = Y.Z. Suppose X_0 denotes CO_2 emission intensity of a reference country and X_i is the CO_2 emission intensity of the ith country. The difference in CO_2 emission intensity between a specified country (X_i) and reference country (X_0) at time t is:

$$\begin{aligned} \Delta X &= X_i - X_0 \\ &= Y_i Z_i - Y_0 Z_0 \\ &= (Y_i - Y_0) Z_0 + (Z_i - Z_0) Y_0 + (Y_i - Y_0)(Z_i - Z_0) \\ &= Z_0 \Delta X + Y_0 \Delta Z + \Delta Y \Delta Z \end{aligned}$$

The term $\Delta Y\ \Delta Z$ is considered as the residual in the general decomposition model. It could be attributed to Y and Z by an equal weight. The residual or interaction term is dependent on the changes of both and if only one of them goes to zero the other effect disappears. The contributions of the factors are:

$$Y_{effect} = Z_0\ \Delta Y + (1/2)\ \Delta Y\ \Delta Z\text{: the carbon factor effect; and}$$

$$Z_{effect} = Y_0\ \Delta Z + (1/2)\ \Delta Y\ \Delta Z\text{: the energy intensity effect}$$

3. DATA SOURCES

The data on CO_2 emission intensity, energy intensity, and carbon factor used in the present study were obtained from International Energy Agency [13]. The purchasing power parities (PPP) converted GDP (US$ using 1990 prices) is chosen to compare the level of economic activities across countries. The exchange rate converted GDP tends to exaggerate the income differences between the developing and industrialized countries [12]. Energy data is used in the form of total primary energy supply (TPES) which is made up indigenous production + imports-exports – international marine bankers ± stock changes. It is measured in million tons of oil equivalent (toe). CO_2 emission is calculated from fuel combustion only using IEA's energy balances and revised 1996 Intergovernmental panel on Climate Change (IPCC) guidelines. The CO_2 emission intensity, energy intensity, and carbon factor are measured in kg CO_2/1990 US$ (PPP), toe/000 of 1990 US$ (PPP), and ton CO_2/toe respectively. Four regions are selected—OECD countries, Asian countries, non-OECD European countries, and Latin American countries. The 20 OECD countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States. The 12 countries considered to be in the Asian group are Bangladesh, Chinese Taipei, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, and Thailand. The eight countries in the non-OECD European group are Albania, Bulgaria, Cyprus, Gibraltar, Malta, Romania, Slovenia, and Slovak Republic. The 22 Latin American countries considered are Antigua, Bolivia, Brazil, Chile, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, and Venezuela.

4. EMPIRICAL RESULTS

To examine the nature of the basic relationship between CO_2 emission intensity and energy intensity or carbon factor, we have used a bivariate regression model. A decomposition technique is also applied to estimate the relevant role of energy intensity and carbon factor to changes in the CO_2 emission intensity with respect to a reference country whose CO_2 emission intensity is the lowest among the countries in a region. The results for the four groups of countries—OECD countries, Asian countries, non-OECD countries, and Latin American countries are given below.

OECD Countries

The correlation coefficient (r) between CO_2 emission intensity and carbon factor (positive) is higher than that between CO_2 emission intensity and energy intensity (positive). This finding indicates that carbon factor has a stronger relation to CO_2 emission intensity than energy intensity. The coefficient of variation (CV), given by the standard deviation (*SD*) as a percentage of the mean, is 28% for the carbon factor and 31% for the energy intensity. That is, energy intensity is more variable than carbon factor even though the relation between CO_2 emission intensity and carbon factor is highly related in OECD countries.

If the average value of aggregate carbon factor (ton CO_2/toe) goes up, the average value of aggregate CO_2 emission intensity is expected to increase by 0.16 kg of CO_2 per 90 US$ (PPP). About 34% variation in CO_2 emission intensity is explained bv the variation in carbon factor. The coefficient of energy intensity (coefficient of Z variable in the 2nd equation in Table 1) is not statistically significant. The energy intensity does not affect CO_2 emission intensity significantly even though the variation in energy intensity among the OECD countries is higher than that of carbon factor. About 13% of the variation in CO_2 emission intensity is explained by the variation in energy intensity. This suggests that the OECD countries utilize energy more intensively. In the OECD countries its share of final energy consumption falls from 62.1% in 1973 to 52.2% in 1998. Energy intensity in the OECD countries declined roughly at a rate of 1.4 per year

Table 1. OECD Countries

Regression:	
a) Regress Y on X: $X = 0.173 + 0.162\ Y$ (1.49) (3.01)* $r^2 = 0.335$	b) Regress Z on X: $X = 0.327 + 0.724\ Z$ (2.74)* (1.63) $r^2 = 0.128$
Correlation Coefficient (r): $r_{XY} = 0.579$ $r_{XZ} = 0.378$	Coefficient of Variation (CV): $CV_Y = 28\%$ $CV_Z = 31\%$

Note: Figures in the parentheses are the *t*-ratios.
*Coefficient estimate is significantly different from zero at 1%.

in the period 1971-1991 (IEA). The main reasons for that improvement were: structural change, efficiency improvement, and fuel substitution.

As a further step, the relative contribution of carbon factor and energy intensity to the changes in CO_2 emission intensity is estimated using the complete decomposition technique. To find this result, Switzerland is chosen as the reference country. Its CO_2 emission intensity is the lowest in our selected 20 OECD countries. We find that the causes of higher CO_2 emission intensity in 19 OECD countries other than Switzerland in 1998 were different. The dominant reason for their higher CO_2 emission intensity was the carbon factor. This is found in 10 out of the 19 OECD countries. The energy intensity causes the higher CO_2 emission intensity in 9 out of 19 OECD countries. Hence, from the standpoint of climate change, the energy intensity is a less useful indicator than carbon factor in the OECD countries.

Asian Countries

The results of the Asian countries are presented in Table 2. The findings for the Asian countries indicate a stronger relation between CO_2 emission intensity and carbon factor than the relation between CO_2 emission intensity and energy intensity. This corresponds to the results obtained for the OECD countries. The higher coefficient of variation for carbon factor identifies that carbon factor is more variable than energy intensity in Asian countries. It contradicts with the finding based on the OECD countries.

If the average value of aggregate carbon factor (ton CO_2/toe) goes up, the average CO_2 emission intensity is expected to increase by 0.26 kg of CO_2 per dollar. Eighty percent of the variation in CO_2 emission intensity is explained by the variation in carbon factor. The second regression equation in Table 2 shows

Table 2. Asian Countries

Regression:	
a) Regress Y on X: $X = -0.076 + 0.259\,Y$ (–1.03) (6.37)* $r^2 = 0.803$	b) Regress Z on X: $X = 0.033 + 1.543\,Z$ (0.20) (2.05)*** $r^2 = 0.296$
Correlation Coefficient (r): $r_{XY} = 0.896$ $r_{XZ} = 0.544$	Coefficient of Variation (CV): $CV_Y = 44\%$ $CV_Z = 36\%$

Note: Figures in the parentheses are the *t*-ratios.
*Coefficient estimate is significantly different from zero at 1%.
****Coefficient estimate is significantly different from zero at 10%.

that if the average value of aggregate energy intensity (toe per dollar) goes up (energy used inefficiently), the average CO_2 emission intensity is expected to increase by 1.54 kg of CO_2 per 90 US$ (PPP). About 30% of the variation in CO_2 emission intensity is explained by the variation in energy intensity. In the Asian countries, the relation between CO_2 emission intensity and carbon factor is strong; and variation in CO_2 emission intensity explained by variation in carbon factor is more than that of the energy intensity.

The decomposition results here are estimated considering Myanmar as the reference country as its CO_2 emission intensity is the lowest in our selected Asian countries. CO_2 emission intensity in 11 Asian countries was higher than that of Myanmar in 1998. The dominant reason for their higher CO_2 emission intensity is the carbon factor. That occurred in 10 out of the 11 Asian countries. This implies that a higher carbon factor leads to the higher CO_2 emission intensity in the Asian countries.

Non-OECD European Countries

Results relating to the non-OECD countries are shown in Table 3. Here energy intensity is more strongly related to CO_2 emission intensity than to carbon factor. The coefficient of variation shows that energy intensity (52%) is more variable than carbon factor (18%). In the non-OECD European countries, energy intensity is more variable and is strongly related to the CO_2 emission intensity. When carbon factor is regressed on CO_2 emission intensity, the coefficient of carbon factor is not statistically significant. The coefficient of energy intensity is statistically significant. About 95% variation in CO_2 emission intensity is explained by the variation in energy intensity. It is higher than the variation of carbon factor (19%). Considering Albania as the reference country in our selected non-OECD European countries (as its CO_2 emission intensity is the lowest) the results of the

Table 3. Non-OECD Countries

Regression:	
a) Regress Y on X:	b) Regress Z on X:
$X = -0.214 + 0.439\ Y$	$X = 0.019 + 2.389\ Z$
(–0.22) (1.08)	(0.20) (9.27)*
$r^2 = 0.189$	$r^2 = 0.945$
Correlation Coefficient (r):	Coefficient of Variation (CV):
$r_{XY} = 0.435$	$CV_Y = 18\%$
$r_{XZ} = 0.972$	$CV_Z = 52\%$

Note: Figures in the parentheses are the *t*-ratios.
*Coefficient estimate is significantly different from zero at 1%.

complete decomposition technique show that the higher CO_2 emission intensity is due to energy intensity (inefficient uses of energy). It is found in all of our selected seven non-OECD countries. That is, higher energy intensity causes higher CO_2 emission intensity in the non-OECD countries.

Latin American Countries

Table 4 presents the results of the Latin American countries. The energy intensity in the Latin American countries is more strongly related to the CO_2 emission intensity than to carbon factor. The energy intensity is more variable than the carbon factor. The coefficients of carbon factor and energy intensity in the regression equations are statistically significant. Here 83% variation in CO_2 emission intensity is explained by the variation in energy intensity that is higher than that of the carbon factor (14%). The results of the complete decomposition technique are calculated selecting Costa Rica as the reference country. The energy intensity plays an important role for higher CO_2 emission intensity. The energy intensity leads to higher CO_2 emission intensity in 14 out of 21 countries. Hence, the energy intensity is a more useful indicator than carbon factor in the Latin American countries.

4.1 VARIATION IN EXPLANATORY FACTORS

Cross-country/region comparisons in CO_2 emission intensity indicate several problems that may not normally occur in a specific country [8]. The different levels of CO_2 emission intensities in different regions may result from different causes. These include large variations in explanatory factors in the data, the measure of economic output, and structural comparability. It is noted that the

Table 4. Latin American Countries

Regression:	
a) Regress Y on X: $X = -0.103 + 0.380\ Y$ (–0.25) (1.78)*** $r^2 = 0.137$	b) Regress Z on X: $X = -0.035 + 1.982\ Z$ (–0.43) (9.89)* $r^2 = 0.830$
Correlation Coefficient (r): $r_{XY} = 0.370$ $r_{XZ} = 0.911$	Coefficient of Variation (CV): $CV_Y = 28\%$ $CV_Z = 77\%$

Note: Figures in the parentheses are the *t*-ratios.
*Coefficient estimate is significantly different from zero at 1%.
****Coefficient estimate is significantly different from zero at 10%.

energy intensity can vary a lot even in countries with a similar level of economic activity. As regards the carbonization index, it is important to note that different energy sources imply an extremely different CO_2/energy relationship. For the same amount of energy consumption, oil, and coal release more CO_2 than natural gas [14]. That is, carbon emission factor for natural gas is low. This value is null for wind power and solar energy (and also for nuclear energy).

In the evolution of the CO_2 emission intensity, the role of energy intensity or carbonization index is purely an empirical issue that, however, cannot be resolved once and for all from the experience of a group of countries during a given period of time. The energy intensity will diminish (energy used efficiently) in response to the change in the relative price of energy. On the other hand, carbonization index will fall if a high carbon tax was imposed on high carbon emitting energy sources. Which of these two factors would be more influential on the CO_2 emission intensity is difficult to predict. The change in energy intensity can be caused by a greater number of factors as compared to carbonization index [8]. It is true that future economic and social systems are impossible without energy use. However, it is also possible to imagine a future in which a complete transition from fossil fuels to other energy sources would occur.

5. CONCLUSIONS

The CO_2 emission intensity varies from country to country. A higher carbon factor leads to a higher CO_2 emission intensity in the OECD and in the Asian countries, whereas in the non-OECD and the Latin American countries the energy intensity causes higher CO_2 emission intensity. The present study demonstrates that CO_2 emission intensity is not generally comparable with respect to the variation in energy intensity and carbonization index. Nevertheless, CO_2 emission intensity cannot be ignored. It is a useful reference point for formulating energy

Table 5. Complete Decomposition Results

Group/region	No. of countries	Reference country	No. of country with high carbon factor effect	No. of country with high energy intensity effect
OECD	20	Switzerland	10	9
Asia	12	Myanmar	10	1
Non-OECD	8	Albania	7	0
Latin America	22	Costa Rica	14	7

and environmental policies in a nation. If the intensity of environmental pressure lessened due to the increase in GDP and if moreover the rate of decrease in CO_2/GDP were higher than the rate of GDP growth, then the economic growth would be environmentally friendly.

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