TULEVAISUUDEN TUTKIMUSKESKUS

TURUN KAUPPAKORKEAKOULU

TUTU–JULKAISUJA

TUTU PUBLICATIONS

5/2002

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ECONOMIC DEVELOPMENT AND ENVIRONMENTAL PERFORMANCE: COMPARISON OF ENERGY USE AND CO_2 EMISSIONS IN OECD AND NON-OECD REGIONS

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Kansikuva Corbis.com

ISBN 951-564-036-9

UDK 339.97
620.9
504.05
504.3

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ABSTRACT

In the empirical study authors analyze long-run historical trends of CO_2 emissions in the world economy. The special focus of the study is a comparison of energy use and CO_2 emissions between OECD and Non-OECD countries.

Basically there are two different ways to reduce CO_2 emissions in the world economy; firstly, by increasing the energy efficiency of the economy; secondly, by fuel switching to less carbon intensive energy production. The OECD countries have implemented both of these strategies, but still the fast economic growth has outweighed the effects of these activities. The growth effect has increased CO_2 emissions in OECD countries by 9000 Mtons between 1971-1999, while the efficiency improvement has decreased the emissions by 6000 Mtons leading to a total increase of 3000 Mtons. The Non-OECD countries failed to carry out fuel switching but in the 1990s the fast improvement in the energy efficiency has almost stagnated the CO_2 emission growth. The growth effect has increased CO_2 emissions in Non-OECD countries by 6200 Mtons between 1971-1999 and the structural effect by about 1000 Mtons, while the efficiency improvement has decreased the emissions by 2000 Mtons leading to a total increase of more than 5000 Mtons.

1. INTRODUCTION

The goal of this article is to make some comparative analyses concerning OECD and Non-OECD countries. The historical cumulative emissions form basic data for the planning of the future participation of different countries in the emission reductions and in the discussion of the burden sharing for the next commitment periods. That is why it is important to analyze the current trends of energy consumption and CO_2 emissions in OECD and Non-OECD countries.

Our analysis is based on decomposition methods, which have been used in recent energy sector analyses. For example, Ang (Ang, 1995a, 1995b), Ang and Zhang (Ang and Zhang, 1999, 2000), Sun (Sun, 1998, 2000), and Sun and Malaska (Sun and Malaska, 1998) have used the decomposition method to compare energy-related CO_2 emission levels between countries and regions. Similar methodology with this article was utilized in the study of Luukkanen and Kaivo-oja (2002a, 2002b, 2002c), which analyzed the Nordic energy systems, ASEAN energy system and key developing countries. This article is a continuation of the well-established research methodology with new global scale comparison framework. Earlier research has concentrated on more or less homogenous country groups, but a new aspect of this research is a comparison of rich OECD countries with poorer non-OECD countries.

2. MATERIALS AND METHODS

2.1. Basic economic and energy system trends: OECD and Non-OECD countries

In this section we present some basic economic and energy system trends of OECD and Non-OECD countries. The data used for the analyses was taken from IEA statistics (IEA 2001). The GDP data was compiled for the individual countries at market prices, in local currency and at annual rates. The data has been scaled up or down to 1995 price levels and then converted to US dollars using the yearly average based on 1995 exchange rates. All the presented data is macro economic, country level data. The analysis here is restricted to a macroeconomic scale and sectoral or engineering bottom-up analyses are not presented.

Figure 1 tells us that the world economy is to a growing extent dominated by OECD countries and the gap between OECD and Non-OECD countries is widening. During the years 1971-1999 the growth of GDP has been almost 15 000 billion dollars in OECD countries compared to the growth of 3 600 billion dollars in Non-OECD countries. The GDP level in OECD countries is about five times higher than in non-OECD countries, but in per capita terms the OECD countries are almost 20 times wealthier than non-OECD countries.

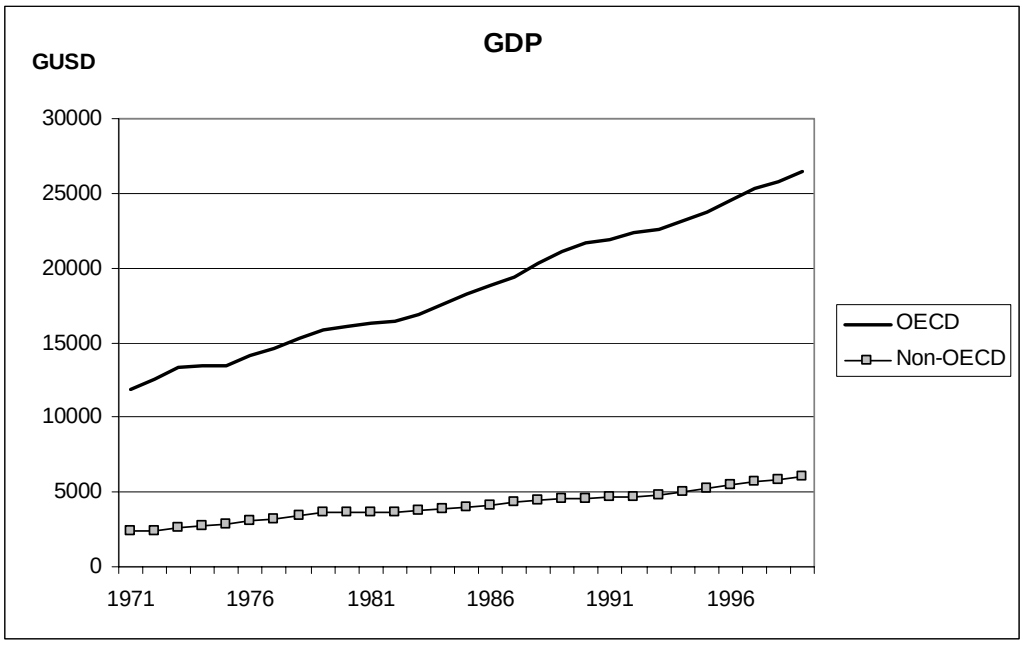

Figure 1. GDP of OECD and Non-OECD countries (billion US dollars in 1995 value) (Data source IEA 2001)

The economic activity is the main driver for the energy use, but also energy intensity of economies is an important factor. When we compare the total primary energy supply (TPES) of OECD and Non-OECD countries (see Fig. 2) we can find out that the difference in the magnitude is much smaller than in the economic production. The growth of TPES has been faster in non-OECD countries up to late 1980s but during the 1990s the largest growth of energy consumption has taken place in OECD countries. These phenomena are also reflected in CO_2 emissions (see Fig. 3).

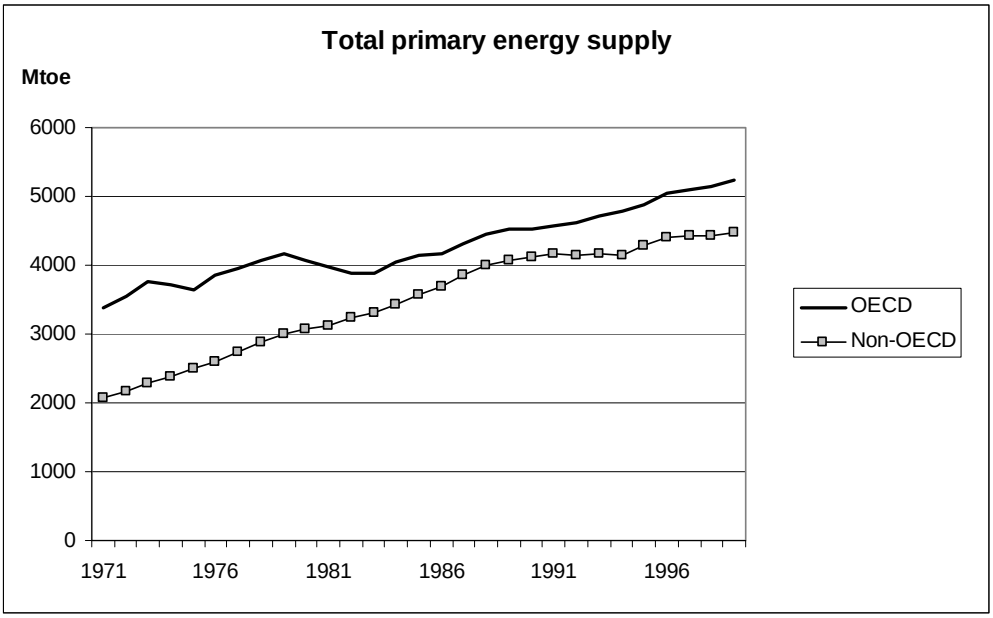

Figure 2. Total primary energy supply (TPES) in OECD and Non-OECD countries from 1960 to 1997 (IEA 2001)

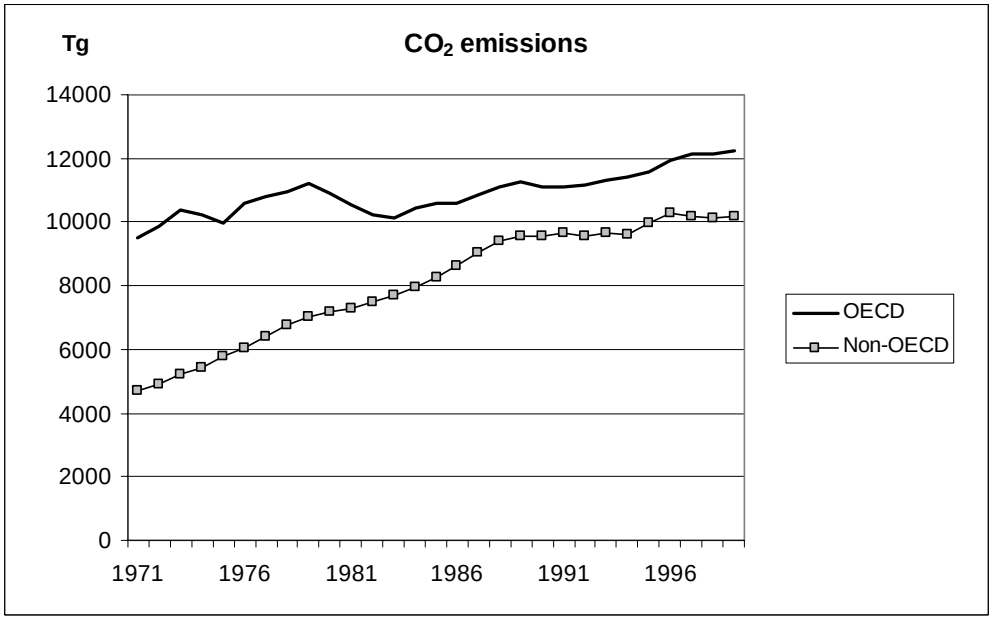

Figure 3. Total CO_2 emissions in OECD and Non-OECD countries in teragrams (Tg = Mton) (Data source IEA 2001)

2.2. Decomposition method in the study

The operationalisation of the productivity ratio of energy P(E,Q) can be defined as:

$$P(E,Q) = \frac{\text{economic outcome}}{\text{energy input}} = \frac{Q}{E} \quad (1)$$

The intensity of energy consumption can be defined, in different sectors (i), as inverse to the previous formula:

$$eI_i = \frac{E_i}{Q_i} \quad (2)$$

where eI_i is the energy intensity in sector i, E_i is energy use in sector i and Q_i is the value added of sector i.

To decompose the energy use of an economy we can use the following equations.

$$E = Q \times \frac{E}{Q} = Q \times \sum_i eI_i \frac{Q_i}{Q} = Q \times \sum_i eI_i s_i \quad (3)$$

where the sum is taken from all sectors and

$$s_i = \frac{Q_i}{Q} \quad (4)$$

is a structural factor of the economy, i.e., the share of sector i production of the total production.

In a similar manner we can decompose the CO_2 emissions P:

$$P = Q \times \frac{P}{Q} = Q \times \sum_i pI_i \frac{Q_i}{Q} = Q \times \sum_i pI_i s_i \quad (5)$$

where

$$pI_i = \frac{P_i}{Q_i} \quad (6)$$

is the sectoral CO_2 intensity.

In Eqs. (3) and (5) the energy use and the CO_2 emission are thus decomposed in relation to the structure of economy.

The aim of this decomposition analysis is to model the changes in energy consumption and emission production. The explanatory variables are: the activity level in the economy, sectoral intensity, and structural shift.

Several methods and indexes have been developed for the purposes of decomposition analysis and they have mainly been used to analyze the energy sector.

Sun (1996) has developed a difference method, which has no residual term unlike other methods. From this Complete Decomposition Model, we have developed the dynamic energy model in the following way:

$$\Delta E = E^t - E^0 \tag{7}$$

$$\begin{aligned}
EQ_{effect}{}^t &= (Q^t - Q^0)\sum_i eI_i{}^0 s_i{}^0 + \tfrac{1}{2}(Q^t - Q^0)\sum_i (eI_i{}^0(s_i{}^t - s_i{}^0) + s_i{}^0(eI_i{}^t - eI_i{}^0)) \\
&+ \tfrac{1}{3}(Q^t - Q^0)\sum_i (eI_i{}^t - eI_i{}^0)(s_i{}^t - s_i{}^0) \\
EI_{effect}{}^t &= Q^0 \sum_i s_i{}^0 (eI_i{}^t - eI_i{}^0) + \tfrac{1}{2}\sum_i (eI_i{}^t - eI_i{}^0)\left[\, s_i{}^0 (Q^t - Q^0) + Q^0 (s_i{}^t - s_i{}^0) \,\right] \\
&+ \tfrac{1}{3}(Q^t - Q^0)\sum_i (eI_i{}^t - eI_i{}^0)(s_i{}^t - s_i{}^0) \\
ES_{effect}{}^t &= Q^0 \sum_i eI_i{}^0 (s_i{}^t - s_i{}^0) + \tfrac{1}{2}\sum_i (s_i{}^t - s_i{}^0)\left[\, eI_i{}^0 (Q^t - Q^0) + Q^0 (eI_i{}^t - eI_i{}^0) \,\right] \\
&+ \tfrac{1}{3}(Q^t - Q^0)\sum_i (eI_i{}^t - eI_i{}^0)(s_i{}^t - s_i{}^0)
\end{aligned} \tag{8}$$

where superscript *0* refers to the base year value and *t* refers to the values of the comparison year varying from n_1 to n_n, in this case from 1971 to 1999.

This model produces an exact decomposition so that:

$$\Delta E = EQ_{effect} + EI_{effect} + ES_{effect}\,. \tag{9}$$

The Q_{effect} is the activity effect that describes the effect of total economic growth on sectoral energy use. The I_{effect} is the intensity effect, which reveals the impact of the technological change and the change in production systems on sectoral energy consumption. The S_{effect} is the structural effect, which reveals the impact of change in the sectoral share of total production on energy consumption.

In a similar way we can develop equations for the decomposition of CO_2 emissions:

$$\begin{aligned}
PQ_{effect}{}^t &= (Q^t - Q^0)\sum_i pI_i{}^0 s_i{}^0 + \tfrac{1}{2}(Q^t - Q^0)\sum_i pI_i{}^0(s_i{}^t - s_i{}^0) + s_i{}^0(pI_i{}^t - pI_i{}^0)) \\
&+ \tfrac{1}{3}(Q^t - Q^0)\sum_i (pI_i{}^t - pI_i{}^0)(s_i{}^t - s_i{}^0) \\
PI_{effect}{}^t &= Q^0 \sum_i s_i{}^0 (pI_i{}^t - pI_i{}^0) + \tfrac{1}{2}\sum_i (pI_i{}^t - pI_i{}^0)\left[\, s_i{}^0 (Q^t - Q^0) + Q^0 (s_i{}^t - s_i{}^0) \,\right] \\
&+ \tfrac{1}{3}(Q^t - Q^0)\sum_i (pI_i{}^t - pI_i{}^0)(s_i{}^t - s_i{}^0) \\
PS_{effect}{}^t &= Q^0 \sum_i pI_i{}^0 (s_i{}^t - s_i{}^0) + \tfrac{1}{2}\sum_i (s_i{}^t - s_i{}^0)\left[\, pI_i{}^0 (Q^t - Q^0) + Q^0 (pI_i{}^t - pI_i{}^0) \,\right] \\
&+ \tfrac{1}{3}(Q^t - Q^0)\sum_i (pI_i{}^t - pI_i{}^0)(s_i{}^t - s_i{}^0)
\end{aligned} \tag{10}$$

To analyze the dynamics of the change we have used Eqs. (8) and (10) to calculate the differences in the long-run time-series data from 1971 to 1999 compared to the reference year 1990, which has been chosen as it is the base year for the Kyoto Protocol (UNFCCC, 1998).

In this analysis the OECD and the Non-OECD countries refer to the different sectors (*i*) of the equations.

3. RESULTS: ANALYSES OF ENERGY AND CO_2 INTENSITY OF THE WORLD REGIONS: OECD AND NON-OECD COUNTRIES

The activity effect (Q_{effect}) on energy use in OECD countries has been about 3 500 Mtoe between 1971-1999 and this corresponds to 77 % of the 1990's level of total energy supply. In Non-OECD countries the growth of energy use due to the activity effect has been about 2 700 Mtoe corresponding to 60 % of the 1990's level. The considerably larger economic growth in the OECD countries has resulted in larger growth in the energy consumption (see Fig. 4).

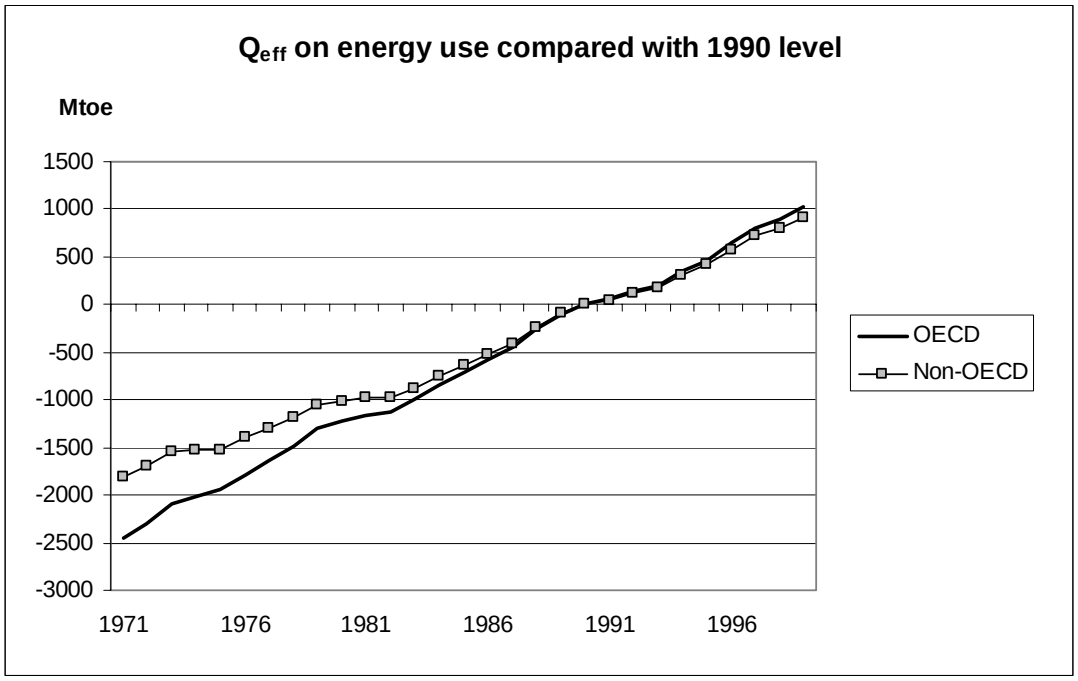

Figure 4. The activity effects on energy consumption (EQ_{effect}) for OECD and Non-OECD countries in absolute values (Mtoe) when compared to their 1990 levels

The structural changes in the world economy have not had considerable effect on energy consumption in the OECD countries (see Fig. 5). In the Non-OECD countries the structural effect has corresponded to mainly less than 5 % in changes in energy consumption. The structural effect on energy consumption seems to be much smaller than the activity effect both in OECD and non-OECD countries.

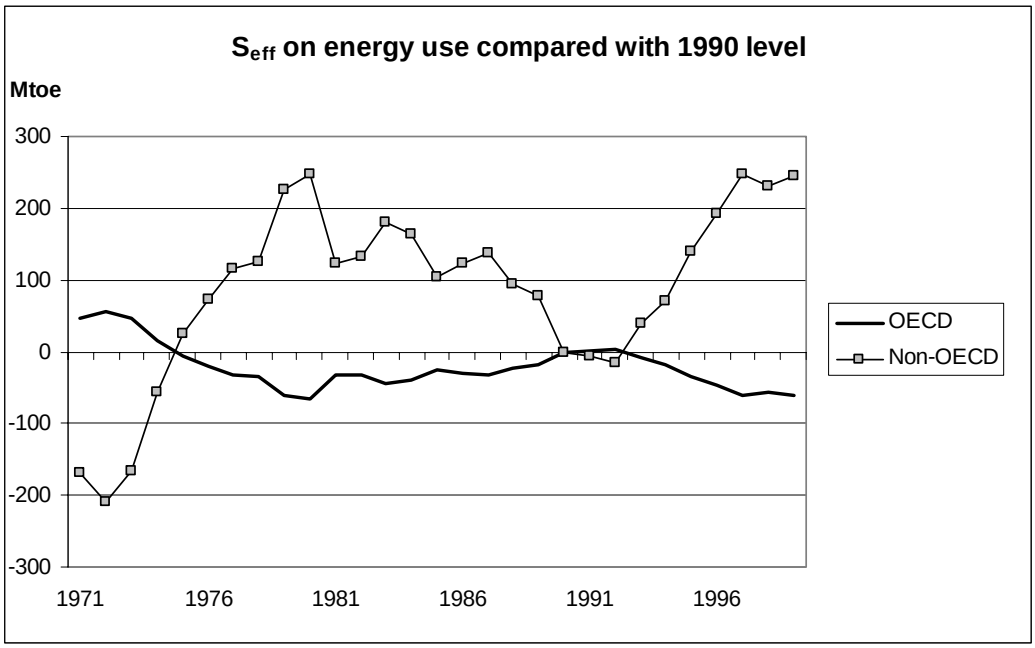

Figure 5. The structural effects on energy use (ES_{effect}) for OECD and Non-OECD countries in absolute values (Mtoe) when compared to their 1990 levels

The energy intensity has changed remarkably in OECD countries during the research period. The intensity effect has decreased energy consumption 1 300 Mtoe from 1971 to 1990 or 28 % of 1990 level. In the 1990s the reduction has been smaller, only 260 Mtoe or 5 % of 1990 level. In the Non-OECD countries there has not been any reduction in the energy use before 1990 due to the intensity effect. After 1990 the reduction due to the intensity effect has been remarkable in the Non-OECD countries resulting in 800 Mtoe energy saving or 18 % of 1990 level (see Fig. 6). The main reason for the efficiency improvement in Non-OECD countries in the 1990's is the development in China and the transition countries (see Luukkanen and Kaivo-oja 2002c).

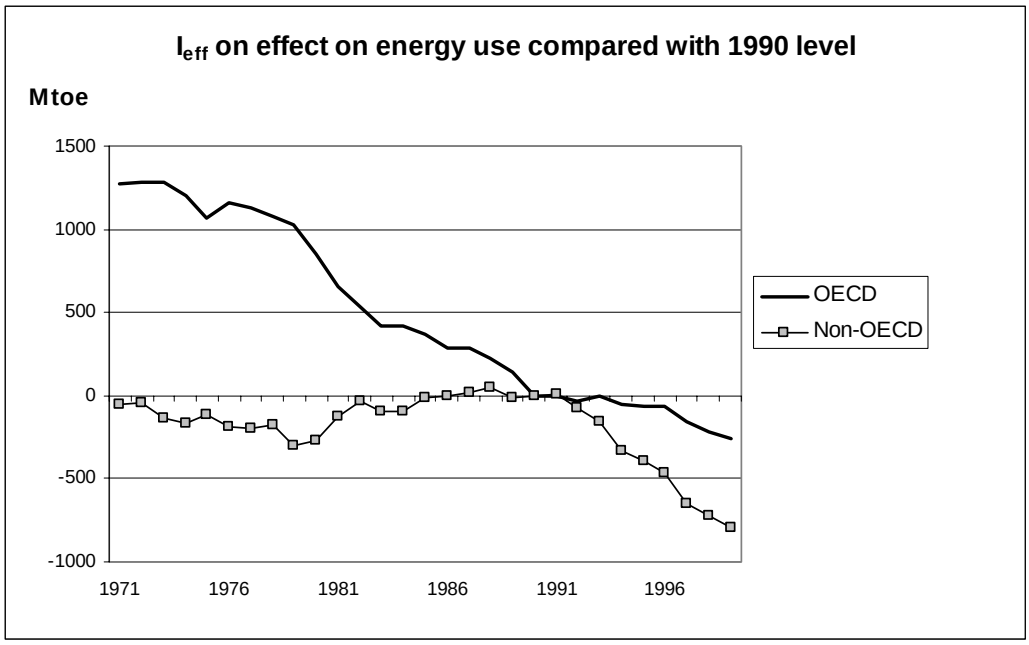

Figure 6. The intensity effects on energy use (EI_{effect}) for OECD and Non-OECD countries in absolute values (Mtoe) when compared to their 1990 levels

The economic growth contributed to a large increase in CO_2 emissions. In the OECD countries the increase has been 9 000 Mtons from 1971 to 1991 due to the activity effect. This equals to 80 % increase compared to 1990 level. In the Non-OECD countries the growth of CO_2 emissions due to activity effect has been about 6 200 Mtons or 65 % of 1990 level (see Fig. 7).

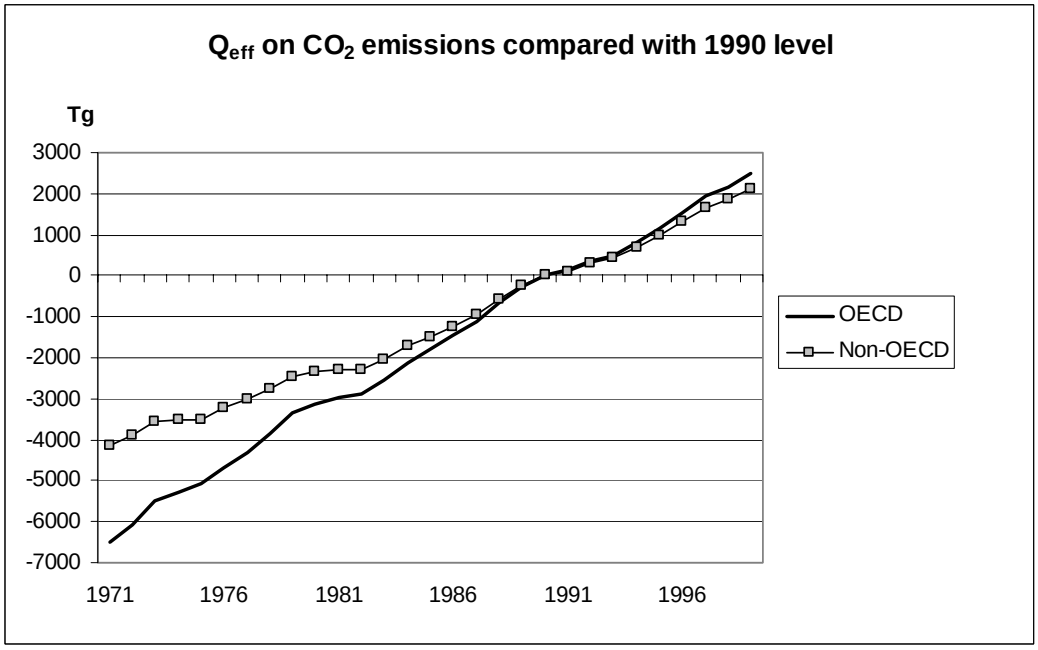

Figure 7. The activity effects on CO_2 emissions (PQ_{effect}) for OECD and Non-OECD countries in absolute values (Tg) when compared to their 1990 levels (Figure 7 about here)

The structural effect on CO_2 emissions is quite similar to the structural effect on energy use (compare Fig. 5 with Fig. 8). In OECD countries the structural effect has decreased CO_2 emissions by 250 Mtons while in Non-OECD countries it has increased emissions by 950 Mtons.

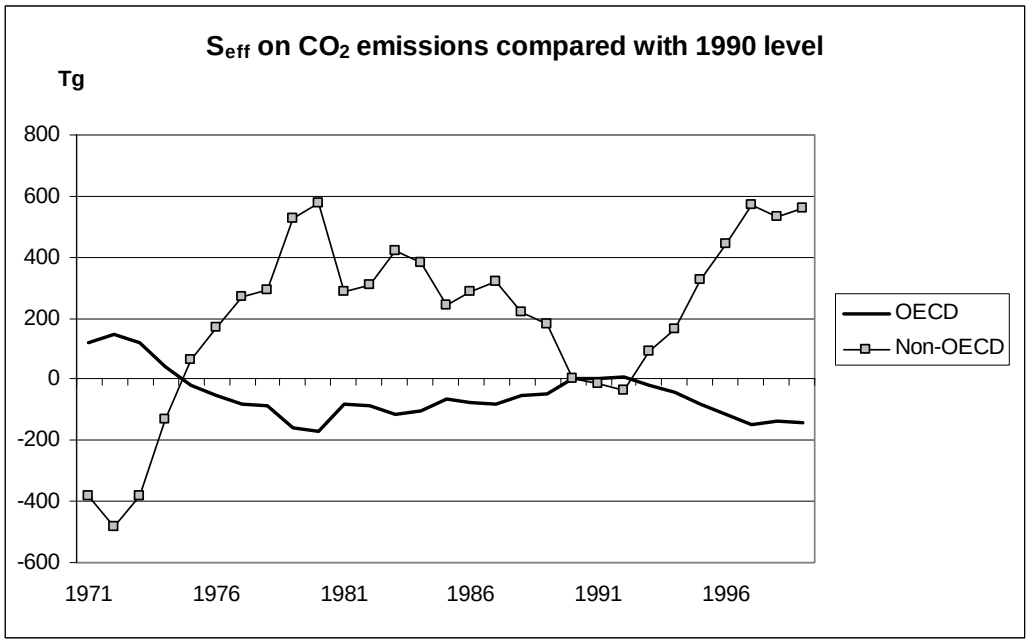

Figure 8. The structural effects on CO_2 emissions (PS_{effect}) for OECD and Non-OECD countries in absolute values (Tg) when compared to their 1990 levels

CO_2 intensity of the OECD economies has improved considerably. During the research period the decrease of the emissions has been about 6 000 Mtons or 53 % due to the intensity effect. In Non-OECD countries there has been a slight increase (3 %) in emissions from 1971 to 1990 due to the intensity effect. After 1990 the change in the intensity effect in Non-OECD countries has resulted in fast decrease in emissions. The CO_2 emissions have decreased 2 000 Mtons or 22 % of 1990 level (see Fig. 9).

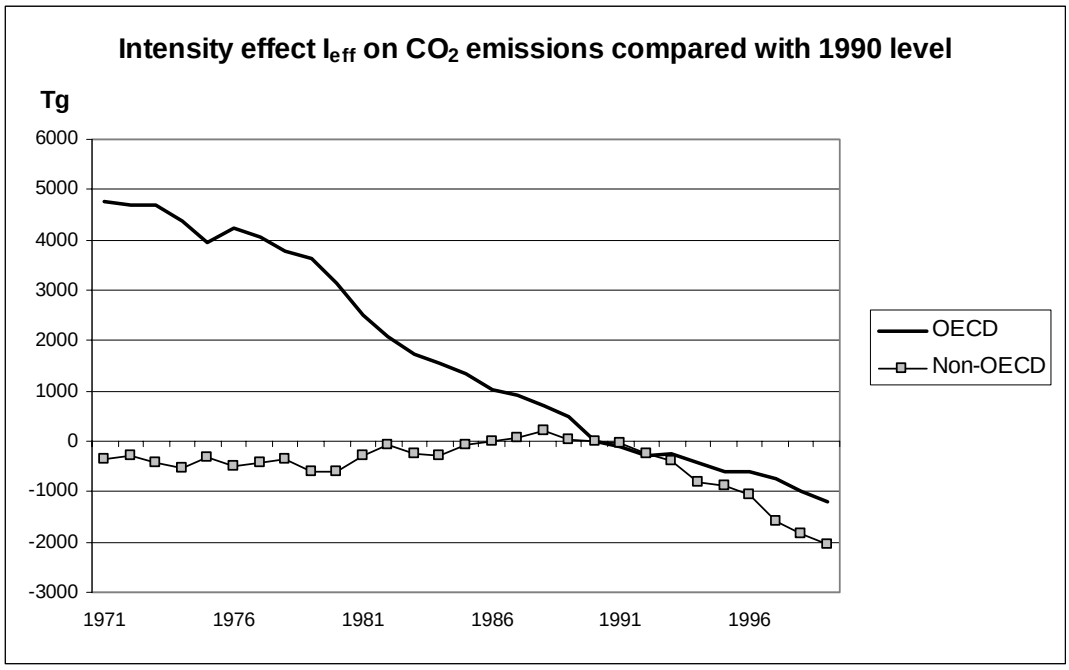

Figure 9. Intensity effects on CO_2 emissions (PI_{effect}) in percentage changes (%) for OECD and Non-OECD countries when compared to their 1990 levels.

Comparison of percentage changes in the intensity effects on energy use and CO_2 emissions gives information of reasons behind the changes of CO_2 emissions. In the OECD countries the CO_2 intensity has decreased faster than the energy intensity indicating that part of the CO_2 emission reductions are caused by fuel switching to less carbon intensive energy production. Part of the decrease in CO_2 emissions is caused by improving energy efficiency (see Fig. 10).

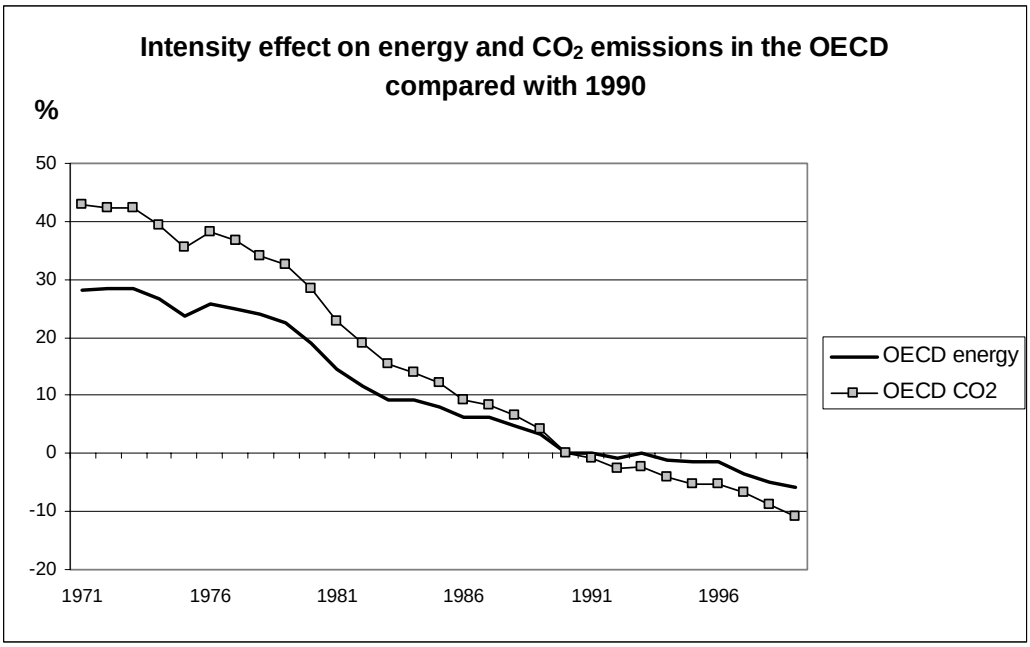

Figure 10. The intensity effects on energy consumption (EI_{effect}) and on CO_2 emissions (PI_{effect}) for OECD countries in percentage changes (%) when compared to their 1990 levels

Figure 11 reveals that there has been almost no fuel switching in Non-OECD countries. The rapid decrease in CO_2 intensity in the 1990s has been caused by the improved energy efficiency.

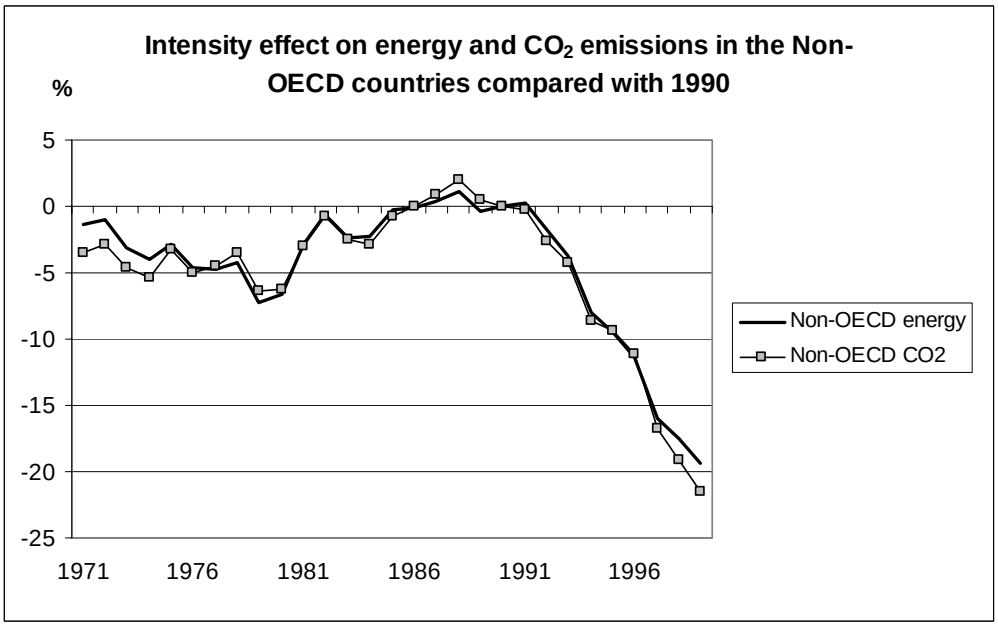

Figure 11. The intensity effects on energy consumption (EI_{effect}) and on CO_2 emissions (PI_{effect}) for Non-OECD countries in percentage changes (%) when compared to their 1990 levels

Figure 12 illustrates the observations we made about fuel switching above. In the Non-OECD countries two counteracting processes have taken place: there has been switch from traditional renewable fuels to fossil fuels (especially in developing countries) and at the same time switch from coal to gas (especially in the transition countries).

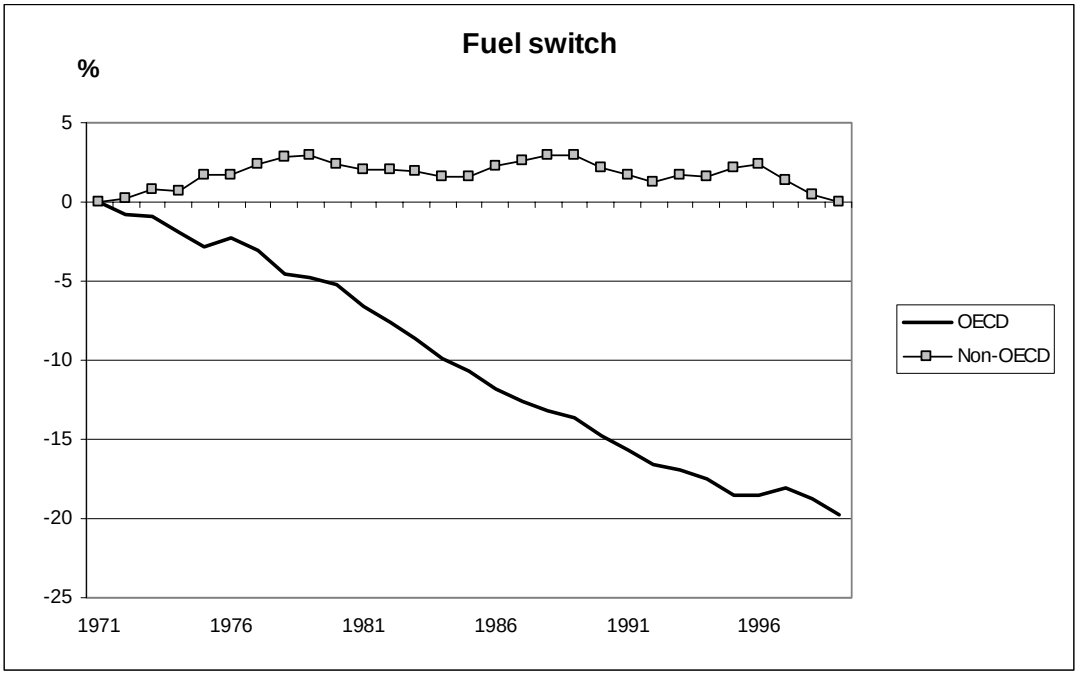

Figure 12. Trends in fuel switching in OECD and Non-OECD countries in the years 1971-1999 (percentage changes)

4. DISCUSSION

In this article we have analyzed CO_2 emissions and energy use in the World Economy. Basically there are two different ways to reduce CO_2 emissions in the world economy; firstly, by increasing the energy efficiency of the economy; secondly, by fuel switching to less carbon intensive energy production. The OECD countries have implemented both of these strategies, but still the fast economic growth has outweighed the effects of these activities. The Non-OECD countries failed to carry out fuel switching but in the 1990s the fast improvement in the energy efficiency has almost stagnated the CO_2 emission growth.

On the basis of the findings of this article fuel switching in Non-OECD countries should be promoted in addition to energy efficiency improvements that have already taken place. To be able to improve the equality in the world the economic growth in the Non-OECD countries should be increased. This means that activities to increase the energy efficiency and fuel switching should be further intensified. In the OECD countries it would be crucial to further increase the energy efficiency and fuel switching to be able to counterbalance the increasing harmful effects of economic growth in the world economy.

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