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GLOBAL TRENDS OF LINKING ENVIRONMENTAL STRESS AND ECONOMIC GROWTH

Total primary energy supply and CO_2 emissions in the European Union, Japan, USA, China, India and Brazil

TUTU PUBLICATIONS 7/2003

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COVER PICTURE	Jyrki Luukkanen
ISBN	951-564-109-8
UDK	330.35 504 339.923 EU 330.15
PRINTED IN	Turku School of Economics and Business Administration, Finland, 2003

CONTENTS

ABSTRACT

In the fields of ecological economics and industrial ecology, de-linking and re-linking environmental impacts from economic growth has become an important element of the scientific debate on growth versus the environment. Beside this debate, the political importance of de- and re-linking necessitates some test to determine whether environmental stress moves into a desired direction or not. The aim of this article is to analyze this important question. For this purpose, we present a theoretical framework including some new concepts of the de-linking and re-linking process as well as the environmental Kuznets curve hypothesis. The main contribution of this article is to operationalize the new theoretical framework for the first time and to analyze the phenomenon of de-linking and re-linking in some of the most important industrialized and developing countries with two indicators of environmental stress. In the case of total primary energy supply, the general global trend in 1973-1999 seems to be weak de-linking. In the case of CO_2 emissions, the EU shows strong de-linking in 1973-1999, Japan, USA and China weak de-linking and India and Brazil expansive re-linking. On the basis of this study, the environmental Kuznets curve hypothesis seems to gain some support for CO_2 emissions and total primary energy supply, both in the industrialized and developing countries.

Keywords: De-linking, re-linking, economic growth, total primary energy supply, CO_2 emissions, environmental Kuznets curve hypothesis

TIIVISTELMÄ

Ympäristötaloustieteen piirissä ympäristövaikutusten irti- ja jälleenkytkeytyminen taloudellisesta kasvusta/taloudelliseen kasvuun on noussut merkittäväksi teemaksi keskustelussa ympäristön ja talouden välisestä suhteesta. Aihe on tärkeä myös poliittisesti, ja päätöksenteon tueksi tarvitaan uusia menetelmiä joiden avulla voidaan selvittää ympäristövaikutusten muutoksen suuntaa talouden makrotasolla. Tässä raportissa esitellään uusi teoreettinen viitekehys ja käsitteistö irti- ja jälleenkytkennän ja niin sanotun ympäristövaikutusten Kuznets-käyrähypoteesin analysointia varten. Viitekehystä sovelletaan empiirisesti kokonaisenergiantarjontaan ja fossiiilisten polttoaineiden käytöstä peräisin oleviin hiilidioksidipäästöihin tärkeimmissä teollisuus- ja kehitysmaissa vuosina 1973-1999. Tulosten perusteella kokonaisenergiantarjonnan yleistrendi globaalilla tasolla on heikko irtikytkentä. Hiilidioksidipäästöissä EU-maiden trendi on vahva irtikytkentä, Japanissa, Yhdysvalloissa ja Kiinassa heikko irtikytkentä sekä Intiassa ja Brasiliassa laajeneva jälleenkytkentä. Ympäristövaikutusten Kuznets-käyrähypoteesi näyttäisi tämän tutkimuksen perusteella saavan jonkinlaista tukea sekä teollisuus- että kehitysmaissa.

Avainsanat: irtikytkentä, jälleenkytkentä, taloudellinen kasvu, kokonaisenergiantarjonta, hiilidioksidipäästöt, Kuznets-käyrä, EKC-hypoteesi

1. INTRODUCTION

In the fields of ecological economics and industrial ecology, "de-linking" environmental impacts from economic growth and "environmental Kuznets curves" (EKC) have become important elements of the scientific debate on economic growth versus the environment since these terms were introduced in the beginning of the 1990s (Yandle et al 2002). Yandle et al (2002) give a description of the EKC: "EKCs are statistical artefacts that summarize a few important aspects of collective human behaviour in two-dimensional space". Despite the existence of empirical evidence supporting the EKC hypothesis for some environmental indicators, many authors have referred to the early stage of development of the theoretical EKC framework (e.g. de Bruyn, 2000; Magnani, 2001; Yandle et al, 2002).

The political importance of de-linking (and re-linking) necessitates some testing to determine whether environmental stress (ES) moves into a desired direction or not. The aim of this article is to analyze this important question. For this purpose, we present a theoretical framework for the analysis and study empirically if we can observe a de-linking process going on, in either some industrialized countries (European Union, Japan and the United States) or in some of the most important developing countries (China, India and Brazil). We perform the empirical analysis using two different but interrelated indicators of environmental stress (ES): total primary energy supply (TPES) and carbon dioxide (CO_2) emissions from fuel combustion. The data source for both indicators is International Energy Agency (IEA, 2002).

The article is organized in the following way: Firstly, we present a theoretical framework for the analysis, including a new conceptualization of the de-linking and re-linking issue, using a triplet of quantities ΔGDP, ΔES, and Δ(ES/GDP) as means to categorize different degrees of de-linking and re-linking. Secondly, we perform an empirical de-linking and re-linking analysis using total primary energy supply and carbon dioxide emissions as indicators of environmental stress. We also test empirically the EKC hypothesis with these indicators. And finally, we present the key findings of the study and compare the results with previous studies focusing on the same countries and the same indicators.

2. A THEORY OF DE-LINKING AND RE-LINKING

The conditions for weak de-linking, strong de-linking and re-linking define, in absolute terms, the relationship between environmental stress and economic growth during a certain time period. In the previous literature, de Bruyn and Opschoor (1997) have defined five stages of de-linking and re-linking (Fig. 1). The whole process is usually called as N-shaped figure. If the last stage of re-linking (stage "e" in Fig. 1) does not take place, one may speak about genuine inverted U-shaped curves or environmental Kuznets curves (Panayotou, 1993, Seppälä et al, 2001).

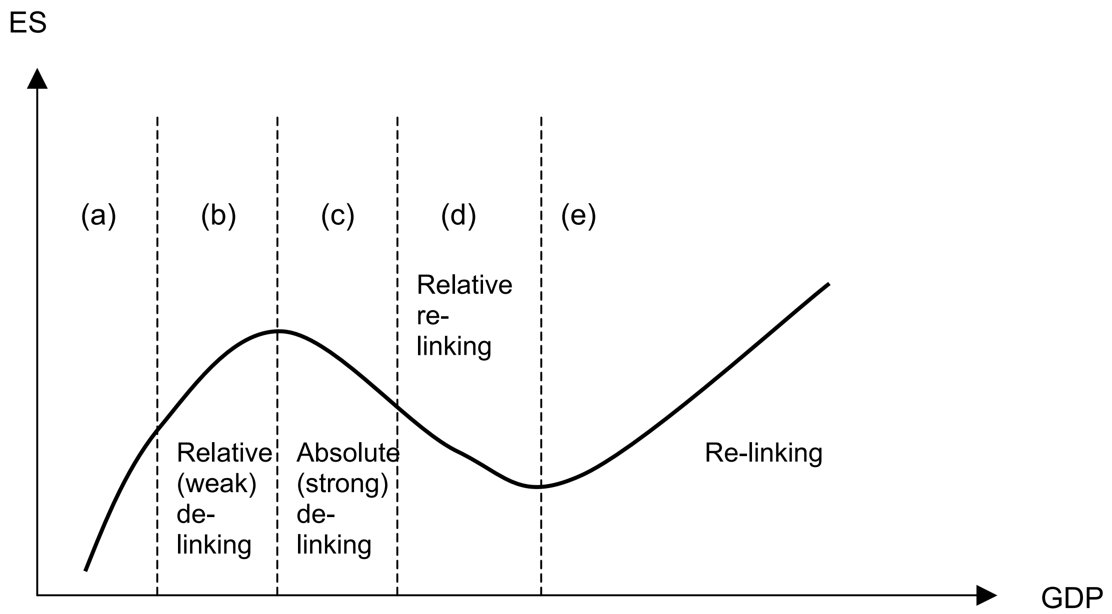

Figure 1. *Stages of the de-linking and re-linking process (de Bruyn, 2000, p. 64, modified by the authors).*

The concept of de-linking refers to the process whereby aggregate economic activity gives rise to reduced environmental stress (ES). De Bruyn (2000, p. 62) has separated two forms of de-linking in a growing economy: weak and strong de-linking. For de-linking to be called weak, the ES intensity must fall. Hence, using the difference between two time moments, a sufficient condition for weak de-linking is

$$\Delta(ES/GDP) < 0$$

Weak de-linking implies that the ES intensity of the GDP decreases over time. However, environmental stress can still increase, albeit necessarily at a lower rate than the growth of the economy. For de-linking to be called strong, environmental stress must reduce over time. This strong de-linking rule implies in difference terms that

$$\Delta ES < 0$$

Some supporters of economic growth have argued that such transformation processes are enhanced by economic growth, and hence ΔES is a non-positive function of ΔGDP. Originally this idea has been labelled as the environmental Kuznets curve (EKC) hypothesis (see e.g. Grossman & Krueger, 1995; Borghesi, 1999). The EKC hypothesis states that economic growth endogenously or "automatically" reduces environmental stress, e.g. through positive income elasticity for environmental goods, technological progress and shifts towards less environmentally intensive activities such as service sectors. The recent literature concerning the EKC hypothesis suggests that there may also be other factors determining the emergence of a downward sloping segment in the EKC than GDP per capita (e.g. de Bruyn, 2000; Magnani, 2001). However, identifying these factors and their effects is not an easy task. Strictly speaking, existence of an EKC curve does not directly tell anything about the reasons for declining environmental stress.

Assuming that the EKC hypothesis holds, there are still doubts if the observed improvements in environmental efficiency can be extrapolated into the future. There may come a time, or income level, where weak or strong de-linking conditions do not hold any more because the possibilities for improving environmental efficiencies may have a technological (e.g. thermodynamic) or economic upper limit. From that point onward, the economic growth component may become more dominant and ES and GDP will be re-linked again, at least until further technical or social innovation breakthroughs in research and development. Such changes may be connected to information technology, energy technology, or other technologies and occur when, for example, more intensive applications of environmental policy instruments are implemented. This prediction is called the re-linking hypothesis (de Bruyn & Opschoor, 1997) and it can be defined as the empirical validation of a process in which ES intensity has been stabilized or starts to rise again, thus in difference terms

$$\Delta(ES/GDP) \geq 0$$

This situation can be termed as weak re-linking, and it implies that the ES intensity of the GDP increases over time. In this situation, environmental stress can still decrease, but this requires a decreasing economy as well. For re-linking to be called strong, environmental stress increases over time. Thus, strong re-linking rule implies in difference terms that

$$\Delta ES \geq 0$$

The de-linking and re-linking issue deals with change in GDP (ΔGDP), change in environmental stress (ΔES) and change in the environmental intensity of GDP, Δ(ES/GDP). To define all possible combinations of different changes, the variables will be put in a system of coordinates (Fig. 2) where the horizontal axis represents GDP and the vertical axis represents environmental stress (ES). A constant relationship between ES and GDP, for instance ES/GDP = 1, can be drawn as a third axis. On the basis of these three axes, we can define six different degrees of the whole de-linking and re-linking process.

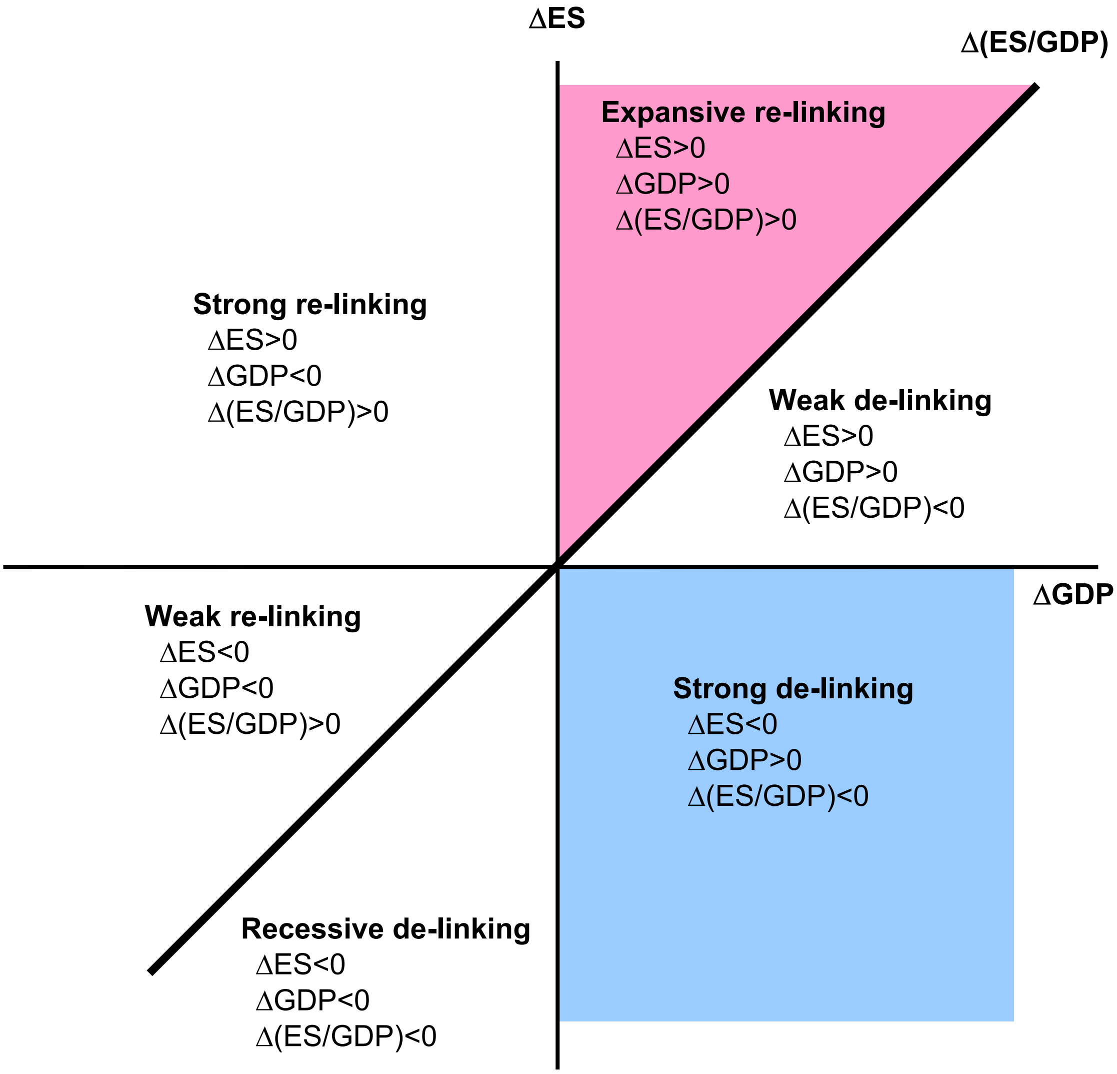

Figure 2. *Definitions of the de-linking and re-linking concepts.*

The area above the line Δ(ES/GDP) in Fig. 2 represents re-linking and the area below the line represents de-linking. For both de-linking and re-linking, three different degrees can be defined and conceptualized according to the direction of changes in the three variables (GDP, ES and ES/GDP after a selected base year).

The area where change in GDP is positive, change in ES is negative and the relationship ES/GDP decreases, can be defined as **strong de-linking**. In practice, strong de-linking means that economic growth is achieved by more efficient technology with decreasing environmental stress. The area with positive changes in both GDP and ES but decreasing ES/GDP can be defined as **weak de-linking**, by following the rules by de Bruyn (2000). In practice, weak de-linking means that despite efficiency improvements, environmental stress increases within GDP growth. The third area of de-linking, where the values of all variables (GDP, ES and ES/GDP) are decreasing, can be defined as **recessive de-linking**. In this case, negative change in GDP causes also negative change in environmental stress, but also efficiency improvements take place at the same time. This is a new concept, because de Bruyn (2000) and others have not taken into account the possibility for decreasing GDP.

The area above the ES/GDP line in Fig. 2 represents re-linking, and three different degrees can be defined like in the case of de-linking. In relation to the analysis by de Bruyn (2000), three new concepts also emerge here. The area where the change of GDP is negative, change in environmental stress (ES) is positive and the relationship ES/GDP increases, can be defined as **strong re-linking**. Here environmental stress increases despite of decreasing economy, because of increasing environmental intensity of the GDP. The area with negative changes in GDP and ES but an increase in the relationship ES/GDP, can be defined as **weak re-linking**. Here environmental stress decreases due to decreasing GDP, although environmental intensity increases like in all other re-linking areas. The third area, where changes both in GDP and ES are positive and the relationship ES/GDP increases, can be conceptualized as **expansive re-linking.** In practice, economic growth is performed by more inefficient technology with increasing environmental stress. This area refers to the re-linking concept in Fig. 1 above. Table 1 still summarizes the above presented degrees of de-linking and re-linking.

Table 1. *Degrees of de-linking and re-linking environmental stress (ES) from economic growth. (GDP)*

Degree of linking	**∆GDP**	**∆ES**	**∆(ES/GDP)**
Strong re-linking	<0	>0	>0
Weak re-linking	<0	<0	>0
Expansive re-linking	>0	>0	>0
Strong de-linking	>0	<0	<0
Weak de-linking	>0	>0	<0
Recessive de-linking	<0	<0	<0

It is obvious that the empirical results of de-linking and re-linking analysis gives different results depending on the chosen indicator of environmental stress – such as material flows, energy consumption, discharge emissions to air, water and soil, and wastes, etc. This is well demonstrated in the empirical EKC studies (e.g. Borghesi, 1999; de Bruyn, 2000; Yandle et al, 2002) but also by the following empirical results where two interrelated indicators, total primary energy supply and carbon dioxide emissions from fuel combustion are used. A logical conclusion from this is that sustainability policy cannot be performed nor based on the analysis of any single indicator; the analyses and policies must be issue-focused instead and detailed enough.

The above presented degrees of de-linking and re-linking indicate also a differentiation of weak and strong EKCs on the basis of the condition for weak and strong de-linking. Thus, a **weak environmental Kuznets curve** can be drawn with environmental intensity of the economy (ES/GDP) in the horizontal axis. A **strong environmental Kuznets curve** can then be drawn with environmental stress (ES) or environmental stress per capita in the horizontal axis. In both cases, the usual choice of GDP per capita can be made for the vertical axis. Regardless of the difference between weak and strong EKC, a possible empirical support for the EKC hypothesis can be interpreted in different ways (cf. de Bruyn, 2000, p. 5; Magnani, 2001). The shape of the EKC can stem from economic growth, from environmental policy, or from some other factor(s). This very important issue is, however, out of the scope of this article.

3. COMPARATIVE DE-LINKING AND RE-LINKING ANALYSIS

In the following, we present an empirical de-linking and re-linking analysis basing on the theoretical framework described above in Figure 2 and Table 1. As noted earlier, we use two different indicators for environmental stress (ES), these are total primary energy supply (TPES) and carbon dioxide emissions from fuel combustion (CO_2). These indicators relate to each other, because CO_2 emission from fuel combustion is a result of the use of TPES (cf. Sun, 1999). However, the relationship between TPES and CO_2 emissions is not constant because of the structure of energy production and fuel mix in different countries, which may also change over time. In the following analysis, we use the data provided by International Energy Agency (IEA) for the years 1973-1999.

Table 2 shows the cumulative changes in GDP, total primary energy supply (TPES) and the relationship between GDP and TPES (TPES/GDP) in 1973-1999 at global level, i.e. in the European Union, Japan, USA, India, China and Brazil. In order to see not only the overall situation but also changes taken place, the analysis is conducted also for three shorter periods, i.e. 1973-1980, 1980-1990 and 1990-1999. The cumulative change is calculated as a difference from the first year of each time period.

Table 2. *Cumulative changes in GDP, total primary energy supply (TPES) and TPES/GDP in the European Union, Japan, USA, India, China and Brazil in 1973-1980, 1980-1990, 1990-1999 and 1973-1999.*

Country/region	1973-1980			1980-1990			1990-1999			1973-1999		
	ΔTPES Mtoe	ΔGDP billion USD	Δ(TPES/GDP) toe/1000 USD	ΔTPES Mtoe	ΔGDP billion USD	Δ(TPES/GDP) toe/1000 USD	ΔTPES Mtoe	ΔGDP billion USD	Δ(TPES/GDP) toe/1000 USD	ΔTPES Mtoe	ΔGDP billion USD	Δ(TPES/GDP) toe/1000 USD
EU-15	55	948	-0.03	109	1513	-0.03	121	1177	-0.01	285	3638	-0.06
Japan	23	438	-0.03	92	993	-0.03	77	376	0.01	192	1807	-0.15
USA	75	854	-0.05	114	1935	-0.08	344	2342	-0.03	534	5130	-0.16
India	49	181	-0.01	117	594	-0.05	121	877	-0.05	287	1652	-0.11
China	167	245	-0.03	280	1116	-0.29	216	2796	-0.23	663	4157	-0.55
Brazil	30	318	-0.02	21	126	0.01	47	235	0.01	98	279	-0.00

Table 3 summarizes the degrees of de-linking and re-linking for total primary energy supply (TPES) in the European Union, Japan, USA, India, China and Brazil from the cumulative differences presented in Table 2. In the case of total primary energy supply, the general global trend during the whole studied period 1973-1999 seems to be weak de-linking. This means that the energy intensities have somewhat decreased, but the economic growth has been much faster causing an increase in total primary energy supply. Weak de-linking characterizes also the shorter periods, but the most recent development in Japan and Brazil has turned to expansive re-linking, which means that energy intensity has even increased.

Table 3. *De-linking and re-linking degrees for total primary energy supply (TPES) in the European Union, Japan, USA, India, China and Brazil 1973-1980, 1980-1990, 1990-1999 and 1973-1999.*

Country/region	1973-1980	1980-1990	1990-1999	1973-1999
EU-15	Weak de-linking	Weak de-linking	Weak de-linking	Weak de-linking
Japan	Weak de-linking	Weak de-linking	Expansive re-linking	Weak de-linking
USA	Weak de-linking	Weak de-linking	Weak de-linking	Weak de-linking
India	Weak de-linking	Weak de-linking	Weak de-linking	Weak de-linking
China	Weak de-linking	Weak de-linking	Weak de-linking	Weak de-linking
Brazil	Weak de-linking	Expansive re-linking	Expansive re-linking	Weak de-linking

Table 4 shows the cumulative changes in GDP, carbon dioxide emissions from fuel combustion (CO_2) and the relationship between GDP and CO_2 emissions (CO_2/GDP) in the European Union, Japan, USA, India, China and Brazil for the years 1973-1999. Like in the case of total primary energy supply, the analysis is conducted for three shorter periods, i.e. 1973-1980, 1980-1990 and 1990-1999, and for the whole time span 1973-1999.

Table 4. *Cumulative changes in GDP, carbon dioxide emissions from fuel combustion (CO_2) and CO_2/GDP in the European Union, Japan, USA, India, China and Brazil in 1973-1980, 1980-1990, 1990-1999 and 1973-1999.*

Country/ region	1973-1980			1980-1990			1990-1999			1973-1999		
	ΔCO_2 Mton	ΔGDP billion USD	$\Delta(CO_2/GDP)$ ton/1000 USD	ΔCO_2 Mton	ΔGDP billion USD	$\Delta(CO_2/GDP)$ ton/1000 USD	ΔCO_2 Mton	ΔGDP billion USD	$\Delta(CO_2/GDP)$ ton/1000 USD	ΔCO_2 Mton	ΔGDP billion USD	$\Delta(CO_2/GDP)$ ton/1000 USD
EU-15	-0	948	-0.10	-171	1513	-0.13	4	1177	-0.05	-167	3638	-0.28
Japan	-22	438	-0.14	150	993	-0.09	109	376	-0.01	236	1807	-0.23
USA	-36	854	-0.18	162	1935	-0.22	693	2342	-0.09	819	5130	-0.50
India	93	181	0.04	260	594	0.02	313	877	-0.02	667	1652	0.04
China	513	245	0.15	863	1116	-0.58	672	2796	-0.56	2048	4157	-0.99
Brazil	62	318	-0.00	15	126	-0.01	99	235	0.04	176	279	0.03

Table 5 summarizes the degrees of de-linking and re-linking for carbon dioxide emissions from fuel combustion (CO_2) in the European Union, Japan, USA, India, China and Brazil from the differences presented in Table 4. From the global point of view of sustainable development, the results are not as coherent as in the case of total primary energy supply. The European Union shows strong de-linking during the whole research period 1973-1999, but the 1990s has meant turning to worse from the environmental point of view, i.e. from strong to weak de-linking. Japan and USA experienced with the EU strong de-linking in the 1970s, but have turned to weak de-linking since then. Weak de-linking dominates the whole period 1973-1999 in these countries.

The general trend in China has also been weak de-linking, although in the 1970s expansive re-linking characterized the Chinese economy. However, China is the only one large developing country in this study where CO_2 intensity has decreased during the whole studied period. India has turned from expansive re-linking towards weak de-linking already in the 1980s, but expansive re-linking still characterizes the whole period 1973-1999. On the other hand, Brazil has performed quite the opposite by turning from weak de-linking towards expansive re-linking in the 1990s, and expansive re-linking already dominates the whole studied period 1973-1999.

Table 5. *De-linking and re-linking degrees for CO_2 emissions from fuel combustion in the European Union, Japan, USA, India, China and Brazil 1973-1980, 1980-1990, 1990-1999 and 1973-1999.*

Country/region	**1973-1980**	**1980-1990**	**1990-1999**	**1973-1999**
EU-15	Strong de-linking	Strong de-linking	Weak de-linking	Strong de-linking
Japan	Strong de-linking	Weak de-linking	Weak de-linking	Weak de-linking
USA	Strong de-linking	Weak de-linking	Weak de-linking	Weak de-linking
India	Expansive re-linking	Expansive re-linking	Weak de-linking	Expansive re-linking
China	Expansive re-linking	Weak de-linking	Weak de-linking	Weak de-linking
Brazil	Weak de-linking	Weak de-linking	Expansive re-linking	Expansive re-linking

4. WEAK AND STRONG ENVIRONMENTAL KUZNETS CURVES

We have also drawn the environmental Kuznets curves illustrating the de- and re-linking analysis. Fig. 3 shows weak EKCs and Fig. 4 strong EKCs for CO_2 emissions from fuel combustion in the EU, USA, and Japan during the years 1960-1999. Fig. 5 shows both weak and strong EKCs for CO_2 emissions from fuel combustion in China, India, and Brazil during the years 1973-1999. Fig. 6 shows weak EKCs and Fig. 7 strong EKCs for total primary energy supply (TPES) in the EU, USA, and Japan during the years 1960-1999. Fig. 8 shows both weak and strong EKCs for TPES in China, India, and Brazil during the years 1973-1999. Like in the de- and re-linking analysis above, also in the EKCs we have used the International Energy Agency (IEA 2002) data.

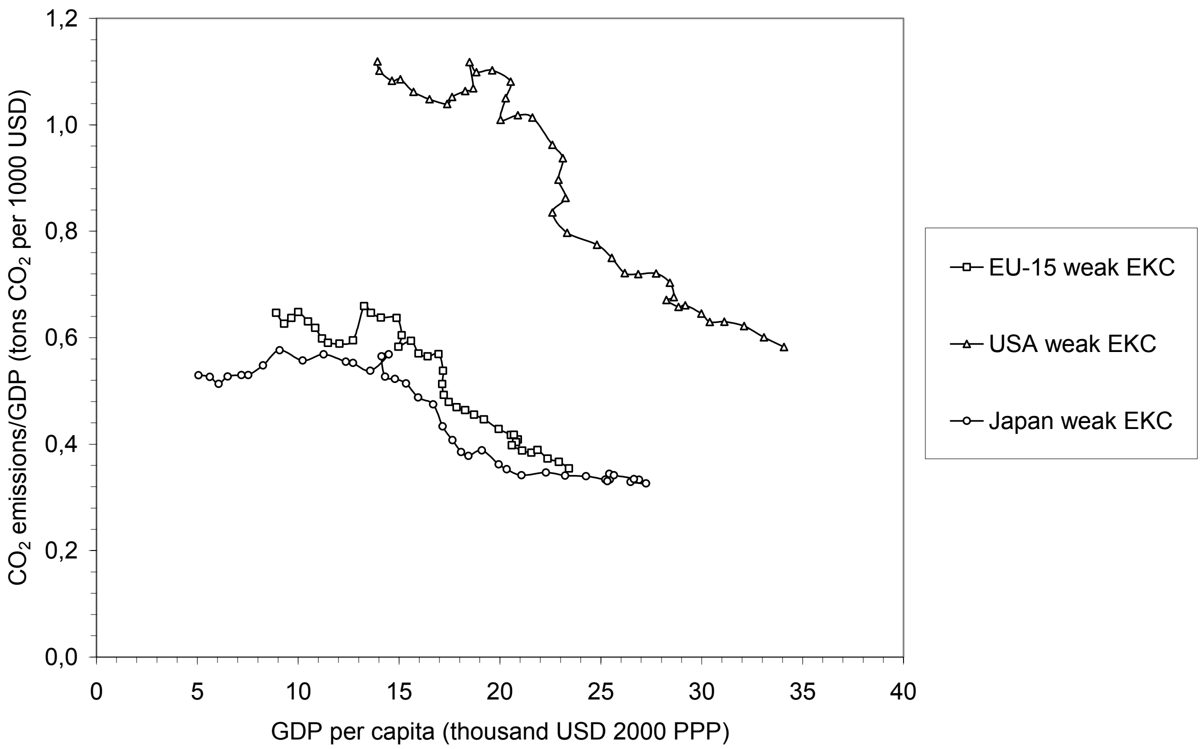

Figure 3. *Weak environmental Kuznets curve for CO_2 emissions from fuel combustion in the European Union, USA, and Japan, 1960-1999.*

On the basis of the weak EKCs presented in Fig. 3, we can draw a conclusion that since the year 1960 the European Union, United States and Japan have improved their CO_2 efficiencies, except just before the 1973-74 oil crisis. In Japan, the decreasing CO_2 intensity seems to be levelling off in the 1990s and turning towards re-linking. Assuming that sometimes before the year 1960 the CO_2 intensities have been growing, the EKC hypothesis seems to gain support from the weak EKC for the industrialized countries, quite clearly for the EU and USA since the oil crisis.

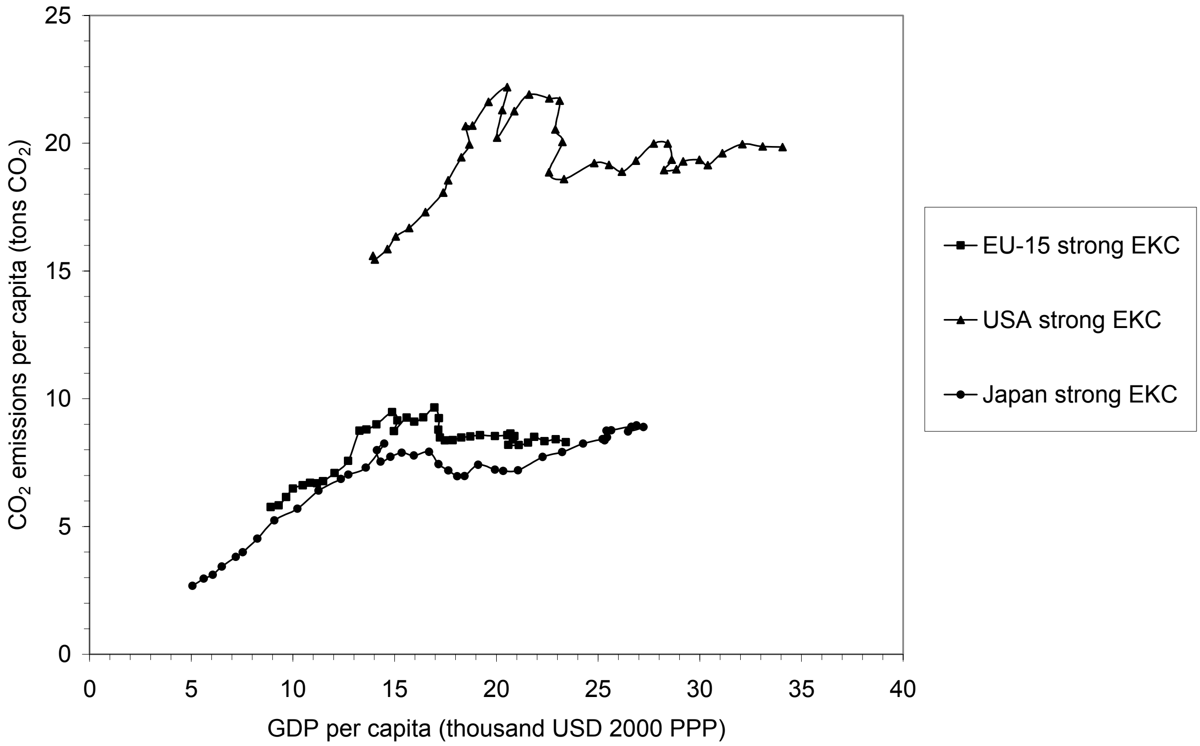

Figure 4. *Strong environmental Kuznets curve for CO_2 emissions from fuel combustion in the European Union, USA, and Japan, 1960-1999.*

When the strong EKC is considered (Fig. 4), the situation is more complicated. Some support for the EKC hypothesis is gained in the EU, but in the USA and Japan only during a short period after the oil crises of the 1970s. Since then, CO_2 emissions per capita have been merely increasing in these countries - albeit at a slower rate.

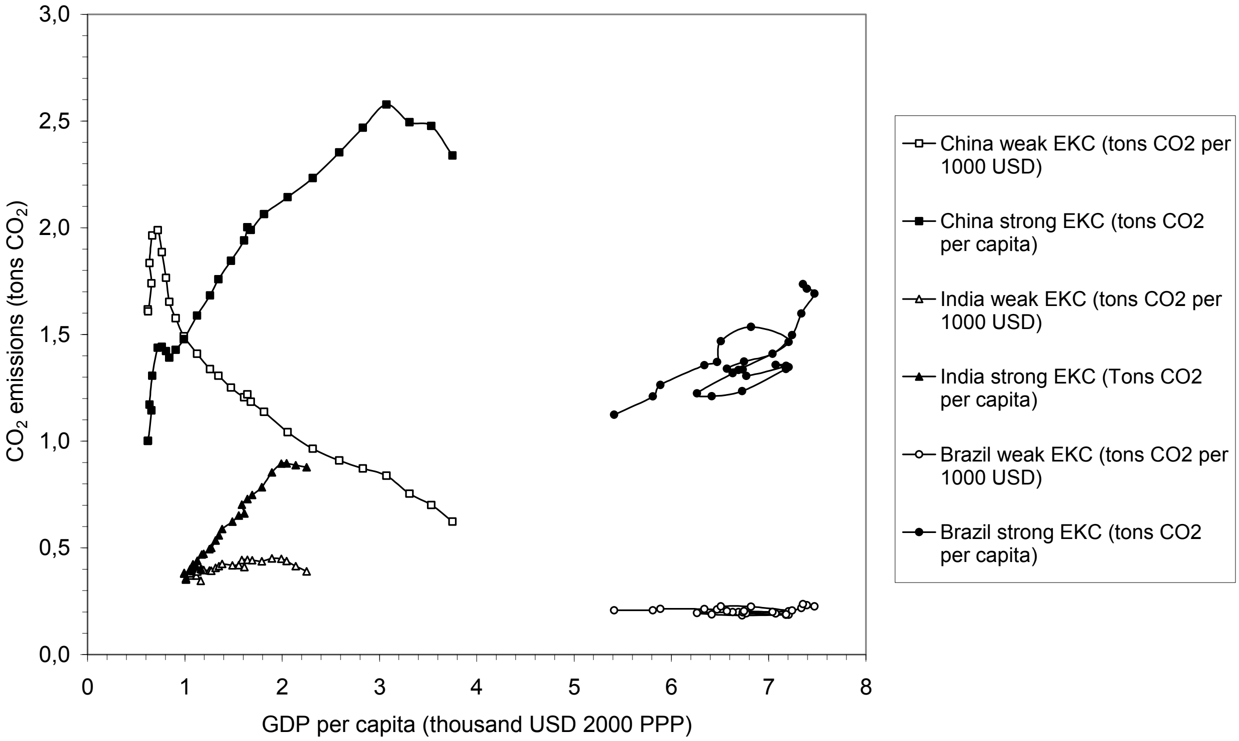

Figure 5. *Weak and strong environmental Kuznets curves for CO_2 emissions from fuel combustion in China, India, and Brazil, 1973-1999.*

In the developing countries, the EKC hypothesis for CO_2 emissions from fuel combustion gains no support in Brazil, neither in the weak nor strong case. In China and India, quite a clear support for the hypothesis can be found both in the weak and strong EKC. In China, CO_2 intensity has decreased very rapidly since the late 1970s but CO_2 emissions per capita have started decreasing only after the mid-1990s. In India, the decrease in CO_2 intensity has been very modest, but like in China, CO_2 emissions per capita have decreased since the mid-1990s.

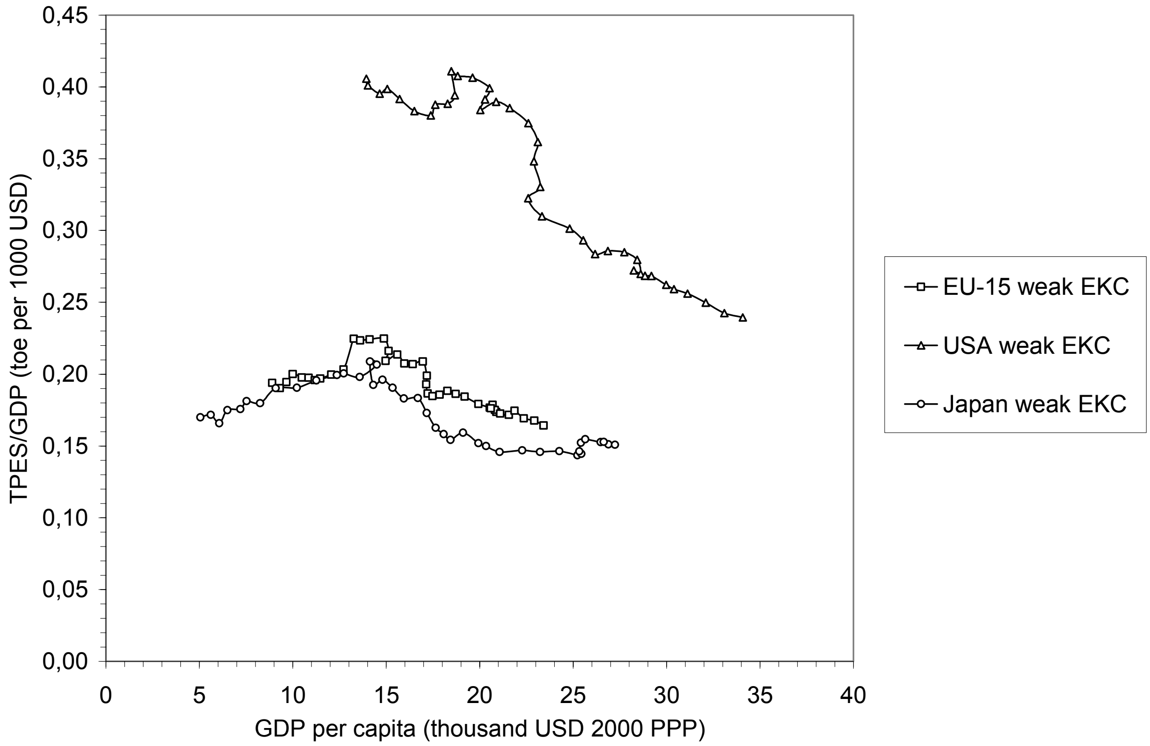

Figure 6. *Weak environmental Kuznets curve for total primary energy supply (TPES) in the European Union, USA, and Japan, 1960-1999.*

Not surprisingly, the EKC curves for total primary energy supply resemble the corresponding curves for CO_2 emissions. In the case of a weak EKC, the EKC hypothesis seems to gain support in the industrialized countries except Japan (Fig. 6).

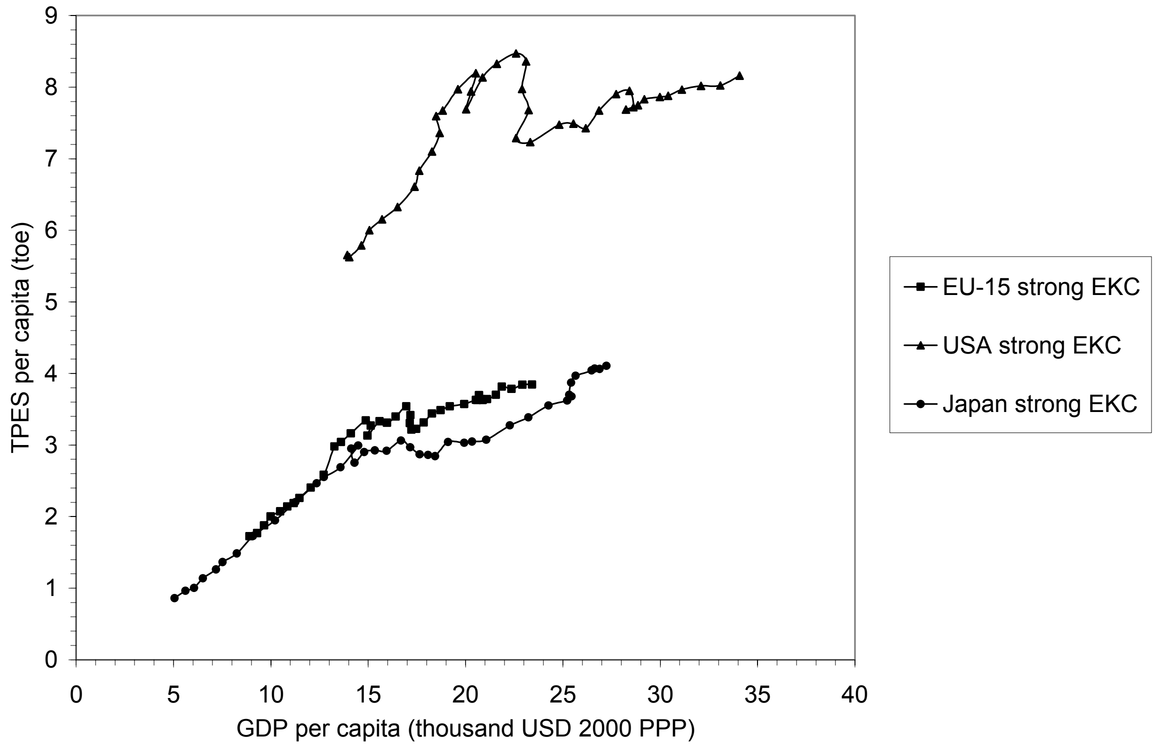

Figure 7. *Strong environmental Kuznets curve for total primary energy supply (TPES) in the European Union, USA, and Japan, 1960-1999.*

In the case of strong EKC, the hypothesis gains no support in the industrialized countries. Total primary energy supply (TPES) per capita has increased in all studied industrial countries after a short period of decline caused by the oil crises in the 1970s (Fig. 7).

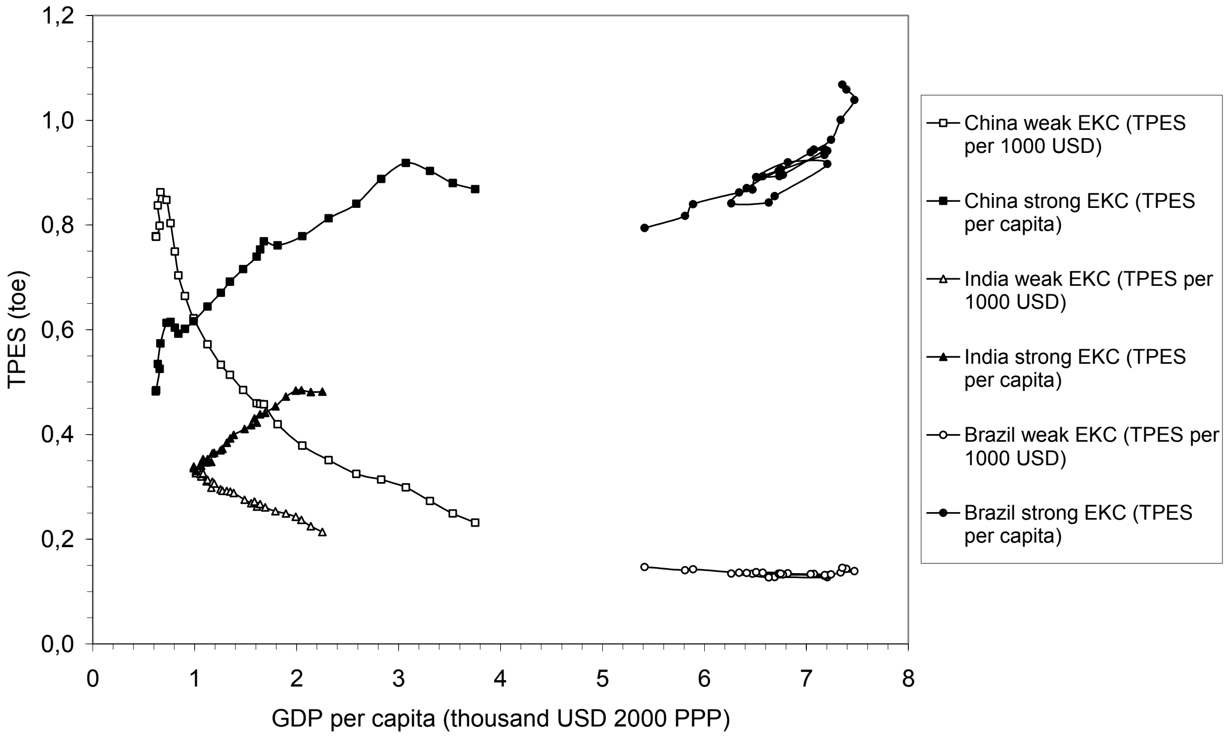

Figure 8. *Weak and strong environmental Kuznets curves for total primary energy supply (TPES) in China, India, and Brazil, 1973-1999.*

The industrialized countries offered support to the EKC hypothesis only in the case of CO_2 emissions. In the developing countries, the EKC hypothesis gains support also in the case of total primary energy supply in China and India, even if the strong EKC is considered. This result indicates that the industrialized countries have turned to less carbon-intensive energy sources than the developing countries. Thus, the choice of total primary energy supply as an indicator of environmental stress may be problematic if comparative analysis is made between industrialized and developing countries.

Recent empirical research indicates that certain types of emissions follow an inverted-U or environmental Kuznets curve as income grows. In this study, we have introduced two theoretical concepts: strong and weak environmental Kuznets curves. We think that this is a clear clarification of the current scientific debate. Table 6 summarizes the results of the empirical analysis for CO_2 emissions from fuel combustion and total primary energy supply (TPES).

Table 6. *Results concerning support for the EKC hypothesis.*

EKC type in a country/region	**Applying for CO_2 emissions**	**Applying for TPES**
EU-15 strong EKC	No	No
EU-15 weak EKC	Yes	Yes
Japan strong EKC	No	No
Japan weak EKC	Yes	Yes?
USA strong EKC	No	No
USA weak EKC	Yes	Yes
China strong EKC	Yes	Yes
China weak EKC	Yes	Yes
India strong EKC	Yes	No
India weak EKC	Yes	Yes?
Brazil strong EKC	No	No
Brazil weak EKC	No	No

On the basis of the results, we can conclude that China is performing well both with total primary energy supply and CO_2 emissions. Both strong and weak EKCs have some kind of an inverted U-shape. On the contrary, Brazil is not performing very well, because neither weak nor strong EKCs resembled the right shape. In other countries/regions except India, we observed only weak EKCs. India can show a strong EKC in the case of CO_2 emissions. Thus, our results seem to be different when compared to the study of de Bruyn et al (1998), where the EKC hypothesis gained no support in the case of CO_2 emissions. However, the analyses focus mainly on different countries: de Bruyn et al (1998) analyzed CO_2 emissions of the Netherlands, United Kingdom, United States and West Germany during the years 1961-1990, and we analyzed the years 1960-1999 for the European Union, Japan and United States, and 1973-1999 for China, India and Brazil. The difference in the results concerning United States can be explained by the difference in time periods. Generally speaking, our analyses found more weak EKCs than strong EKCs.

5. CONCLUSIONS

In this article, we presented some new concepts and definitions for the de-linking and re-linking as well as environmental Kuznets curve (EKC) theory. In previous literature the concepts of relative (weak) de-linking, absolute (strong) de-linking, and re-linking have been presented. In this article, we offered a more detailed conceptual definition for the different degrees of the de-linking and re-linking process and defined a weak and strong version of the EKC. The main contribution of this article is to operationalize these new concepts for the first time and analyze the phenomenon of de-linking and re-linking in some of the most important industrialized and developing countries.

Despite lack of data before the year 1960, the EKC hypothesis seems to gain support in the industrialized countries since the oil crises in the 1970s, with CO_2 emissions per GDP (weak EKC) and CO_2 emissions per capita (strong EKC) as indicators of environmental stress. In the case of total primary energy supply, only weak EKCs of the EU and USA gave support to the EKC hypothesis. The situation in the developing countries seems to be very interesting: according to Fig. 4 and Fig. 6 above, the EKC hypothesis seems to have the inverted U-shape with both indicators in China, but only with CO_2 emissions from fuel combustion in India although India shows quite a slow development in GDP per capita in comparison to China or Brazil. However, the EKCs in Brazil do not show the shape of the EKC hypothesis. Not surprisingly, the findings of this study indicate that the weak EKC gains more empirical support than the strong EKC.

Previous studies have noted that the inverted U-curve is not stable over a longer time period and the reductions of environmental stress should be considered as a temporary phenomenon (de Bruyn, 2000, p. 5 and p. 221). The results of our study seem to be supporting de Bruyn's conclusion in the case of Japan, with both indicators considered. De Bruyn (2000, p. 221) has also noted that the observed phase of dematerialization from 1973 until the mid-1980s can be primarily explained as a result of the oil crises, which rapidly changed the technological and organizational structures of economies in the industrialized countries. According to our study, the oil crises of the seventies seem not to have caused such a great transformation impact on the developing countries, due to a low level of oil use before the crises (see also Luukkanen and Kaivo-oja, 2002 and Kaivo-oja and Luukkanen, 2002).

When we tested environmental Kuznets curve (EKC) hypothesis on the part of the shape of the EKC, we observed that in the case of total primary energy supply (TPES), the EKCs resembled the inverted U-shape in some of the industrialized countries. Weak de-linking has been a typical trend among both industrialized and developing countries for total primary energy supply, but the EKC did not have the right kind of shape in Brazil and India.

In the case of CO_2 emissions, we observed strong de-linking in the European Union during the whole studied period 1973-1999 and during the shorter periods 1973-1980 and 1980-1990. Japan and USA performed weak de-linking during the whole studied period 1973-1999, and strong de-linking only during the first period 1973-1980. The EKCs had some kind of an inverted U-shape in all industrialized countries studied, most significantly in the European Union. In the developing countries, we could also find similar shape of the EKC for CO_2 emissions in China and India. This result seems to challenge the conclusion made by Ekins (1997, p. 815) who stated that despite improvements in some indicators, notably of some air pollutants, the developing countries seem to be experiencing continuing, serious environmental degradation of all fronts.

On the basis of this study, we can note that any typical trend related to the de-linking or re-linking process and to the EKC curves cannot be found. The results vary from country to country and from time period to another, and from environmental indicator to another. Among the industrialized countries, the European Union has succeeded somewhat better in sustainability performance than Japan or USA. Among developing countries, China has succeeded better than India or Brazil in sustainability performance.

The minimum policy implication of the empirical findings presented in this study is that there is a need to deepen the sustainability analysis at global level, in order to diagnose the most important bottlenecks where the advancement of sustainability should be enhanced by the world community. In practical measures this obviously means strengthening the execution and measures of the United Nations Johannesburg statement.

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