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Economic Growth, Energy Demand and the Environment –
Empirical Insights Using Time Series and Decomposition Analysis

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Abbreviations

ADF test	Augmented Dickey Fuller test
AIC	Akaike Information Criterion
APEC	Asia-Pacific Economic Cooperation
ARDL	Autoregressive Distributed Lag
AUS	Australia
AUT	Austria
BEL	Belgium
BGD	Bangladesh
BGR	Bulgaria
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
bn	Billion
BRA	Brazil
BTU	British Thermal Units
C	CO_2 Emission Coefficient
CAN	Canada
CE	Cointegrating Equation
C_{eff}	Emission Coefficient Effect
CHE	Chemical and Petrochemical Industry
CHN	People's Republic of China
CO	Carbon Oxide
CO_2	Carbon Dioxide
CYP	Republic of Cyprus
CZE	Czech Republic
DEU	Germany
DNK	Denmark
e	Natural logarithm of per capita total final energy demand
E	Total Energy Consumption in the Industry sector
E_{act}	Activity Effect (Energy Consumption)
ECM	Error Correction Model
ECMT	European Conference of Ministers of Transport
ECT	Error Correction Term
E_{int}	Intensity Effect (Energy Consumption)

EKC	Environmental Kuznets Curve
EM	CO_2 Emissions from the Consumption of Fossil Fuels
EM_{act}	Activity Effect (CO_2 Emissions)
EM_{emf}	Emission Factor Effect
EM_{int}	Intensity Effect (CO_2 Emissions)
EM_{mix}	Fuel Mix Effect
EM_{str}	Structure Effect (CO_2 Emissions)
EOR	Enhanced Oil Recovery
ESP	Spain
E_{str}	Structure Effect (Energy Consumption)
ET	Total CO_2 Emissions from the Transport Sector
EU	European Union
EUR19	Aggregate of 19 European Union and OECD members (Germany, France, Great Britain, Italy, Spain, the Netherlands, Poland, Belgium, Sweden, Austria, the Czech Republic, Finland, Greece, Portugal, Hungary, Denmark, Ireland, Slovakia, Luxemburg)
EUR23	Aggregate of 23 European Union members (Germany, France, Great Britain, Italy, Spain, the Netherlands, Poland, Belgium, Sweden, Austria, the Czech Republic, Romania, Finland, Greece, Portugal, Hungary, Denmark, Ireland, Slovakia, Bulgaria, Luxemburg, Cyprus, Malta)
FIN	Finland
FM	Fuel Mix Variable
FM_{eff}	Fuel Mix Effect
FOD	Food and Tobacco Industry
FPES	Primary Energy Supply of Fossil Fuels
FRA	France
FSU	Former Soviet Union
FSUREG	Region of the Former Soviet Union (= FSU)
G-11	Group of Eleven (Jordan, Croatia, Ecuador, Georgia, El Salvador, Honduras, Indonesia, Morocco, Pakistan, Paraguay, Sri Lanka)
G-7	Group of Seven (The United States, Japan, Great Britain, Germany, Canada, France and Italy)
GBR	Great Britain
GCC	Gulf Cooperation Council

GDP	Gross Domestic Product
GHG	Greenhouse Gas
GRC	Greece
HUN	Hungary
I	Energy Intensity
IBRD	International Bank for Reconstruction and Development
IDA	Index Decomposition Analysis
IDN	Indonesia
IEA	International Energy Agency
I_{eff}	Energy Intensity Effect
IND	India
IPCC	Intergovernmental Panel on Climate Change
IPS test	Im, Pesaran and Shin panel unit root test
IRL	Ireland
IRN	Islamic Republic of Iran
IRS	Iron and Steel Industry
ITA	Italy
JAMA	Japan Automobile Manufacturers Association
JPN	Japan
KOR	Republic of Korea (South Korea)
LLC test	Levin, Lin and Chu panel unit root test
LMDI	Log Mean Divisia Index
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LR	Long Run
LUX	Luxemburg
MAC	Machinery Industry
MAIC	Modified Akaike Information Criterion
MET	Non-Ferrous Metals Industry
MEX	Mexico
M	Fuel Mix Variable
MLT	Malta
MS	Modal Split

MS_{eff}	Modal Split Effect
Mt	Million Tons
MWI	Malawi
MYS	Malaysia
NLD	The Netherlands
NMM	Non-Metallic Minerals Industry
NO_x	Nitrogen Oxide
NZL	New Zealand
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of Petroleum Exporting Countries
p	Natural logarithm of the index of real energy prices for industry and households
PAK	Pakistan
PAP	Paper, Pulp and Printing Industry
P_{eff}	Population Effect
PHL	Philippines
pkm	Passenger kilometres
POL	Poland
POP	Population
PP test	Phillips-Perron unit root test
PPP	Purchasing Power Parity
PRT	Portugal
Q	Activity Level
R/P ratio	Reserves-to-Production ratio
RAR	Reasonably Assured Resources
ROU	Romania
S	Share of Fossil Fuels; Activity Share
SAU	Saudi Arabia
S_{eff}	Substitution Effect
SGP	Singapore
SIC	Schwarz Information Criterion
SO_2	Sulfur Dioxide
SPM	Suspended Particulate Matter

SR	Short Run
STAN	Structural Analysis Database (OECD)
SVK	Slovak Republic
SWE	Sweden
t	Tons
TEX	Textile and Leather Industry
TFC	Total Final Consumption
THA	Thailand
tkm	Thousand Kilometres
TPES	Total Primary Energy Supply
TRA	Transport Equipment Industry
TUR	Turkey
TWN	Taiwan
U.S.	United States
UK	United Kingdom
UNFC	United Nations Framework Classification for Fossil Energy and Mineral Resources
US	United States
USA	United States of America
USD	U.S. Dollars
VA	Value Added
VAR	Vector Autoregression
VECM	Vector Error Correction Model
vkm	Vehicle Kilometres
VMT	Vehicle Miles Travelled
WBCSD	World Business Council for Sustainable Development
WEO	World Energy Outlook (IEA Publication)
WOD	Wood and Wood Products Industry
y	Natural logarithm of real per capita GDP
Y_{eff}	Income Effect
ZAF	South Africa

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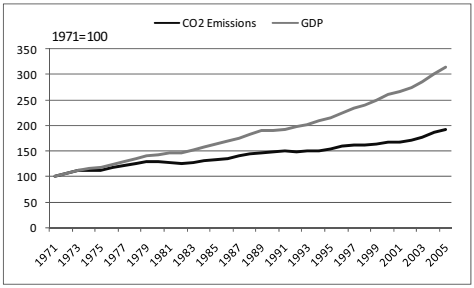
1. Preface

Industrialization and increasing wealth in emerging markets – especially in China and India – as well as intensifying globalization and the associated boost in transportation have lead to an unexpected rise of global energy demand in the last decade. According to the Reference Scenario in the 2007 issue of the IEA World Energy Outlook, the global primary energy demand is projected to grow by 55% between 2005 and 2030. The developing countries with fast growing populations contribute 74% of this increase, China and India alone 45%.[1] The bulk of global energy supply is coming from fossil fuels. Although renewable energy sources are promoted heavily in industrialized countries, they will neither be able to replace fossil fuels, nor fill the gap between growing demand and the current level of supply of fossil resources in the near future. This has important implications for the world's energy security. We will see a growing dependence of consuming countries on oil and gas imports as well as a reduction of geographic supply diversity with an increasing market dominance of the Middle East and Russia. As a geopolitical consequence, energy will greatly determine foreign relations in the future as the uninterrupted flow of energy will mainly depend on the political and economic stability of the producer regions. Furthermore there will be more competition among consumer countries for energy supplies following this growing energy import dependency. Another consequence of the soaring demand in combination with the existing global energy mix is accelerating climate change due to increasing greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change Fourth Assessment report[2], most of the observed rise in global average temperatures since the mid-20th century is very likely[3] related to the increase in anthropogenic greenhouse gas (GHG) concentrations. The combustion of fossil fuels is the largest contributor to GHG emissions and carbon dioxide (CO_2) is responsible for about 95% of the energy-related emissions. Thus fossil fuel combustion is the single largest human influence on climate. While emissions have doubled in the period between 1971 and 2005, real gross domestic product (GDP) has reached three times the value of the base year (see Figure 1). But although declining global CO_2 emissions per unit of GDP could be observed in many industrialized countries, strong economic growth in emerging markets has led to a worrying

[1] See IEA (2007b), p.73.
[2] IPCC (2007)
[3] In the IPCC terminology "very likely" means a likelihood of occurrence of > 90%.

rise in global CO_2 emissions in the last years. Similar to the supply security problem GHG emissions can be tackled by either increasing the share of renewable energy sources or by the implementation of strict energy conservation measures as well as efficiency technologies. During the negotiation process for a new post Kyoto climate regime energy saving measures play a vital role, as energy saving is far easier in the short term than restructuring the primary energy mix. However a lot of countries, mostly developing countries, fear that such policy measures will harm their economic development.



Data Source: IEA; author's own illustration.

Figure 1: World CO_2 emissions from fuel combustion and real GDP[4]

Since the oil crisis of the 1970's the relationship between energy consumption, environmental pollution and economic growth has been analyzed and discussed in many different ways. Especially between 2004 and 2008 energy became an issue once again as global economic growth led to an enormous increase in oil prices.

The IEA World Energy Outlook 2006 stated: "The world is facing twin energy-related threats: that of not having adequate and secure supplies of energy at affordable prices and that of environmental harm caused by consuming too much of it. …" and "…the need to curb the growth in fossil-energy demand, to increase geographic and fuel-supply diversity and to mitigate climate-destabilising emissions is more urgent than ever."[5] In the very same year Sir Nicholas Stern published his widely acknowledged and discussed "Stern Review on the Economics of Climate Change"[6], presenting scientific evidence for the economic

[4] World GDP in 2000-USD using Purchasing Power Parities (PPP).
[5] See IEA (2006), p.37.
[6] Stern (2006).

impacts of climate change and necessary policy responses. The subsequent IEA World Energy Outlook 2007 focused on the role of China and India as the "emerging giants of the world economy and international energy markets."[7] It became clear that the growth rates of these countries and the impact on global energy demand would pose a big challenge to the present energy system and existing efforts to combat climate change. Thus a transition to a more secure, lower-carbon energy system seemed inevitable, but only without the risk of undermining economic and social development. Furthermore, soaring energy prices fueled the fear of a recurrence of the oil crisis of the 1970s and reports about continuous resource depletion led to a revival of the peak oil theory initially developed by Marion King Hubbert in the 1950s.[8]

These developments and discussions were the starting point for this text. The idea was to dig deeper into the mechanisms of energy use and economic development and to assess which are the main factors behind energy savings and a reduction of energy related carbon dioxide emissions. As discussed in detail in the following chapters, the existing empirical literature only gives a limited view on these issues as to the methods used, to the geographical and sectoral coverage, as well as the time periods observed. This thesis thus aims at empirically giving insights about the relationship between energy consumption, economic growth and CO_2 emissions on a global scale. The analysis is carried out for the top energy consumers and CO_2 emitters worldwide with a special emphasis on the European Union and some focus countries for the detailed investigation of the industry and transport sector. In addition, recent panel cointegration and decomposition methods are used to analyze detailed data of the last 25-35 years.

The statements or assertions below are to be tested within this context:

- There is a mutual interrelationship between economic growth and energy demand.
- Developing and emerging economies are more energy-dependent than the economies of highly developed countries.

[7] See IEA (2007b), p.41.
[8] See Hubbert (1956).

- Rising energy productivity in combination with changes in the primary energy mix with less carbon content is the best strategy to mitigate energy related emissions.
- The reduction of CO_2 emissions within the industrial sector in Western European countries was only possible due to a relocation of energy intensive subsectors to developing and newly industrialized countries.

The text is structured as follows. Chapter 2 gives a description of the relationship between energy, economic growth and the environment. The current energy system in terms of availability and use of energy sources is illustrated. The question is discussed, whether pollution is rising inevitably with economic growth, or if emissions fall again at a certain level of per capita income (Environmental Kuznets Curve).

In Chapter 3 the causality between energy prices, energy consumption and economic growth is analyzed empirically. This empirical investigation applies cointegration and error correction techniques and consists of two parts. In the first part the bivariate relationship between energy and GDP is examined for the 15 biggest global energy consumers between 1978 and 2005. In the second part, energy prices are added as a third variable.

Chapter 4 uses decomposition analysis of the change in carbon dioxide emissions in order to analyze the relationship between emission growth and changes in underlying factors using the Log Mean Divisia Index (LMDI) method. It covers the biggest carbon dioxide emitting countries and regions that together account for over 80% of total emissions worldwide in the period from 1971 to 2005.

The industry sector is one of the largest consumers of energy and also one of the largest energy-related CO_2 emitters. Chapter 5 gives insights into the mechanisms of change in industrial energy consumption as well as changes in CO_2 emissions for ten manufacturing industries in five European countries by using the same decomposition technique.

The transport sector is one of the largest and fastest growing sources of greenhouse gas emissions. As a consequence Chapter 6 provides an overview of energy consumption and emission drivers in the transport sector, with empirical examples for the United States, Japan and Germany. The second part of the

chapter focuses explicitly on road transport, as this sub-sector has the lion's share of transport energy use and emissions.

Finally Chapter 7 summarizes the empirical results and presents policy implications as well as further need for research beyond the scope of this text.

This thesis uses recent panel cointegration and error correction models to test for causality between energy consumption and economic growth. It also assesses the role of energy prices in this context using real indices of energy prices for industry and households, while most other studies on this issue use consumer price indices as a proxy. In chapters four to six a perfect index decomposition method LMDI1 is applied to analyze the underlying factors of energy consumption patterns and CO_2 emissions. Time series decomposition is used because the decomposed results given by this approach can better explain the underlying mechanisms of change in energy use. Most other decomposition studies of energy consumption and CO_2 emission use period wise decomposition, which is based on the data of two benchmark years, and the data for the intervening years are discarded. These period wise decomposition results are less informative and hence may not result in superior representation to the real situation. Apart from rising incomes and population, these models also account for fuel mix in primary and final energy consumption as well as structural effects. The analysis is not only conducted on an aggregate level, but also for the industry and transport sector.