Drivers of Carbon Emission Intensity in the Developed and the Developing Countries

A dissertation submitted in partial fulfillment of requirements for Masters of Arts in Economics (Energy Economics)

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Student Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

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Executive Summary

Climate change is one of the most pressing issue that the World is currently faced with. Thanks to unabated release of greenhouse gases into the atmosphere majorly because of incessant industrialization over the past century and a half, there has been an increase in mean global temperatures at surface level by around 0.65 degree Centigrade to around 1.06 degree Centigrade. Major greenhouse gases (GHG) include water vapour, carbon dioxide, methane, nitro oxides and tropospheric ozone. While the now industrialized developed countries share the historic responsibility for such concentration of GHGs, the now developing countries can be blamed for incremental amounts of such gases currently being emitted into the atmosphere. Also the literature studied lacks a comprehensive study on the factors driving the carbon intensity of an economy. This dissertation aims to conduct such a study in the context of both the developed and developing economies in order to understand the underlying dynamics of GHG emissions and therefore recommend suitable policy measures. For this purpose panel data analysis for two sets of countries- developed (consisting of US, Japan, Norway, France and UK) and developing (India China, Brazil, South Africa and Indonesia) are used. From literature carbon intensity is hypothesized to have a relationship with energy intensity, fossil fuel intensity and urbanization.

In case of the developed countries, energy intensity was found to be the most significant variable impacting the carbon intensity at the aggregate level. Analysing the trends depicted by the respective variables, it was concluded in case of developed nations, enhanced utilization of energy for economic activity was compensated by the utilization of energy efficient technologies and cleaner fossil fuels like natural gas. Taken together, this has had a net impact of reducing the carbon intensity of such economies. In case of the developed countries, energy intensity was found to be the most significant variable impacting the carbon intensity at the aggregate level. Such countries should continue to promote energy efficiency improvements in their economic activities along while enhancing substitution of fossil fuel based energy sources with clean and green sources like natural gas, renewables and biofuels. Also promoted should be low carbon lifestyles, especially in urban areas so as to reduce the carbon footprint in such countries.

In the case of developing countries on the other hand, taken as a whole energy intensity is the only variable that has a statistically significant influence on carbon intensity. Fossil fuel intensity (though insignificant) shows a rising trend. Falling energy and carbon intensities and rising fossil

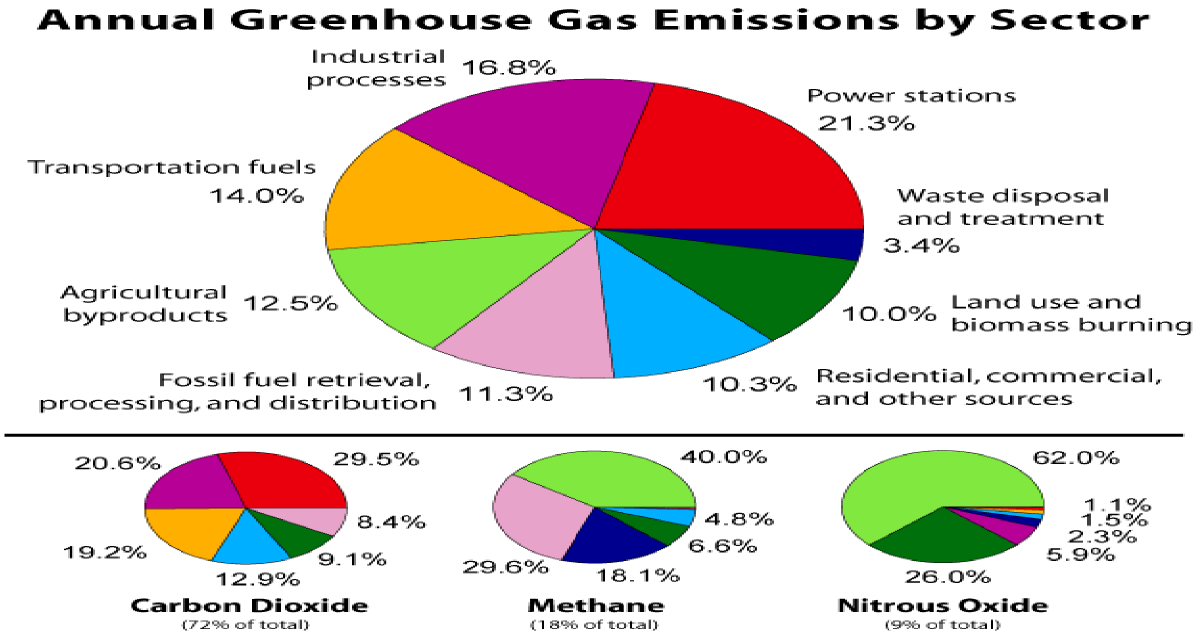
fuel intensity points to the impact of efficiency improvements undertaken in such economies. Also, despite the insignificance of the variable proportion of urban population, it can be argued better urban planning is key to reduce the energy intensity and thus carbon intensity of such economies. Recommendations for such countries include enhanced adoption of energy efficient technologies and equipment, reduction in the consumption of fossil fuels and promotion of renewables. Also required is the provisioning for the usage of relatively clean fuels like 'LPG' and electricity in rural areas along with implementation of better urban management programmes in such countries.

1. Introduction

Climate change is one of the most pressing issue that the World is currently faced with. Thanks to unabated release of greenhouse gases into the atmosphere majorly because of incessant industrialization over the past century and a half, there has been an increase in mean global temperatures at surface level by around 0.65 degree Centigrade to around 1.06 degree Centigrade. Major greenhouse gases (GHG) include water vapour, carbon dioxide, methane, nitro oxides and tropospheric ozone. It has been observed that since 1750, the concentration of carbon dioxide and methane in the atmosphere have increased by 36% and 148% respectively. It is expected that unchecked global warming is likely to lead to rise in global temperatures in the range of 1.8-4 degree Centigrade by 2100 from 1989-99 levels, rise in sea levels in the range of 0.18-0.58 levels between 1999-2100, changes in precipitation patterns and increase occurrence of extreme events. Such occurrences will have the potential to wipe out small low lying countries from the World map along with loss of biodiversity and would cause physical and economic losses to people worst affected by climate change.

Extensive use of fossil fuels since industrial revolution is noted to be the primary driver of such increase in concentration of greenhouse gases. Following charts gives a glimpse of the major drivers of GHG emissions.

Figure 1: Green House Emissions by Sector



It can therefore be observed that the energy sector takes the maximum blame for the enhanced emissions of GHGs.

Historically, the now developed industrialized nations are the ones with the primary responsibility for enhancing the concentration of GHGs into the atmosphere. Although the implementation of the Kyoto Protocol saw reduction in emissions by major developed economies like U.K and Germany, the following charts show various aspects that fix the responsibility of global warming on developed economies.

Figure 2: Annual Regional Carbon Emissions from Fuel Combustion (1971-2009)

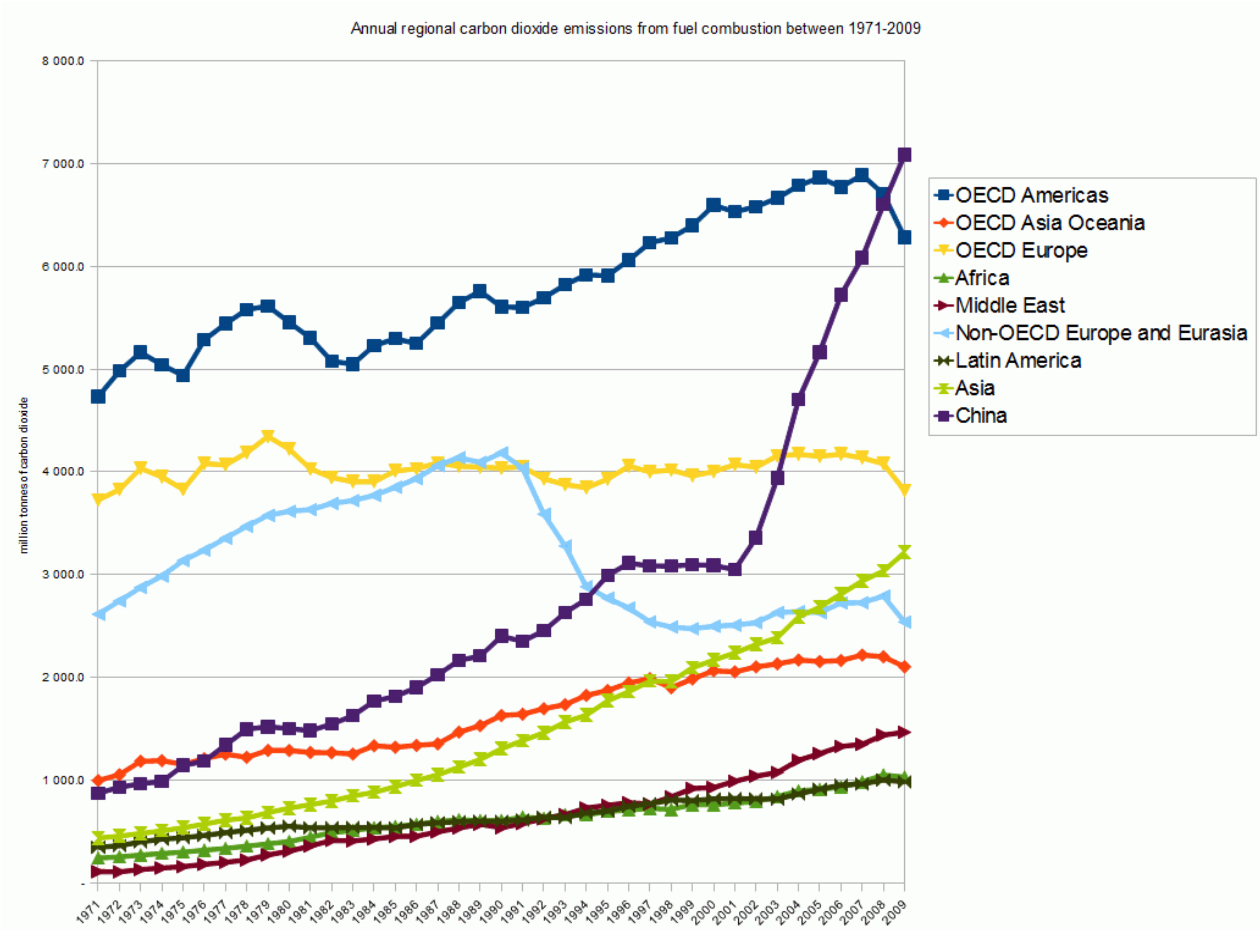


Figure 3: Regional Annual Per Capita Carbon Emissions from Fuel Combustion (1971-2009)

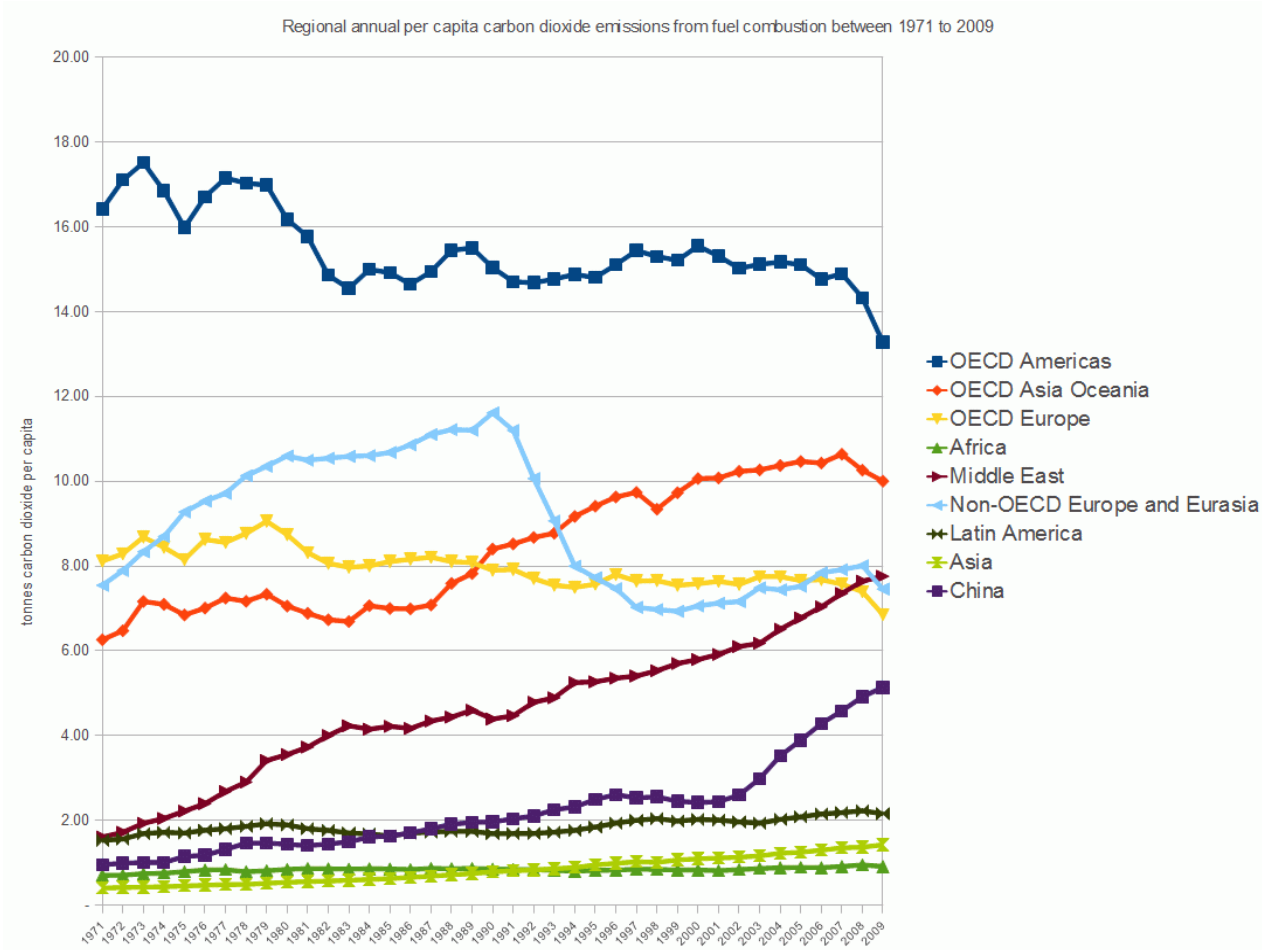


Figure 4: Total Greenhouse and CO_2 Emissions 2012

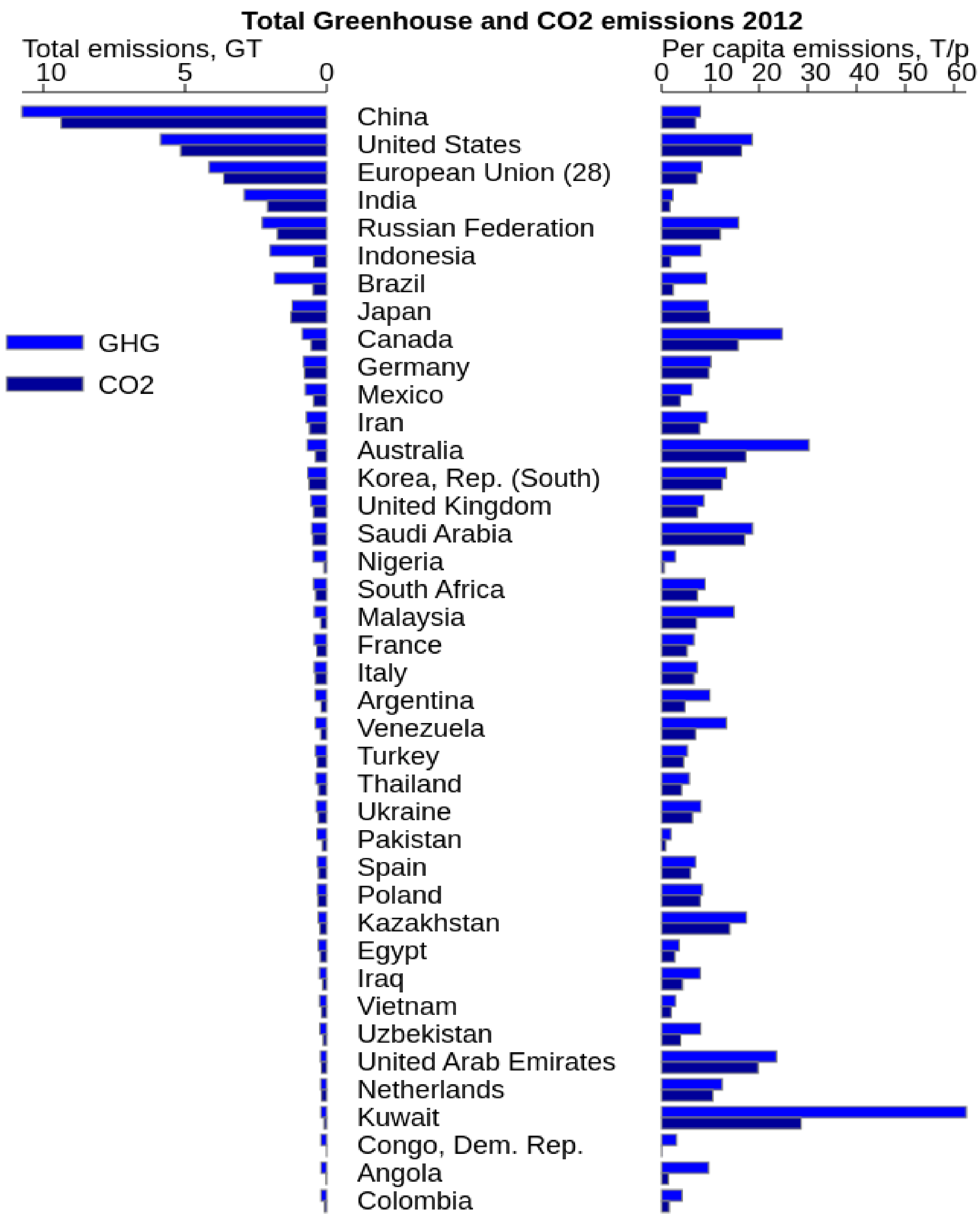
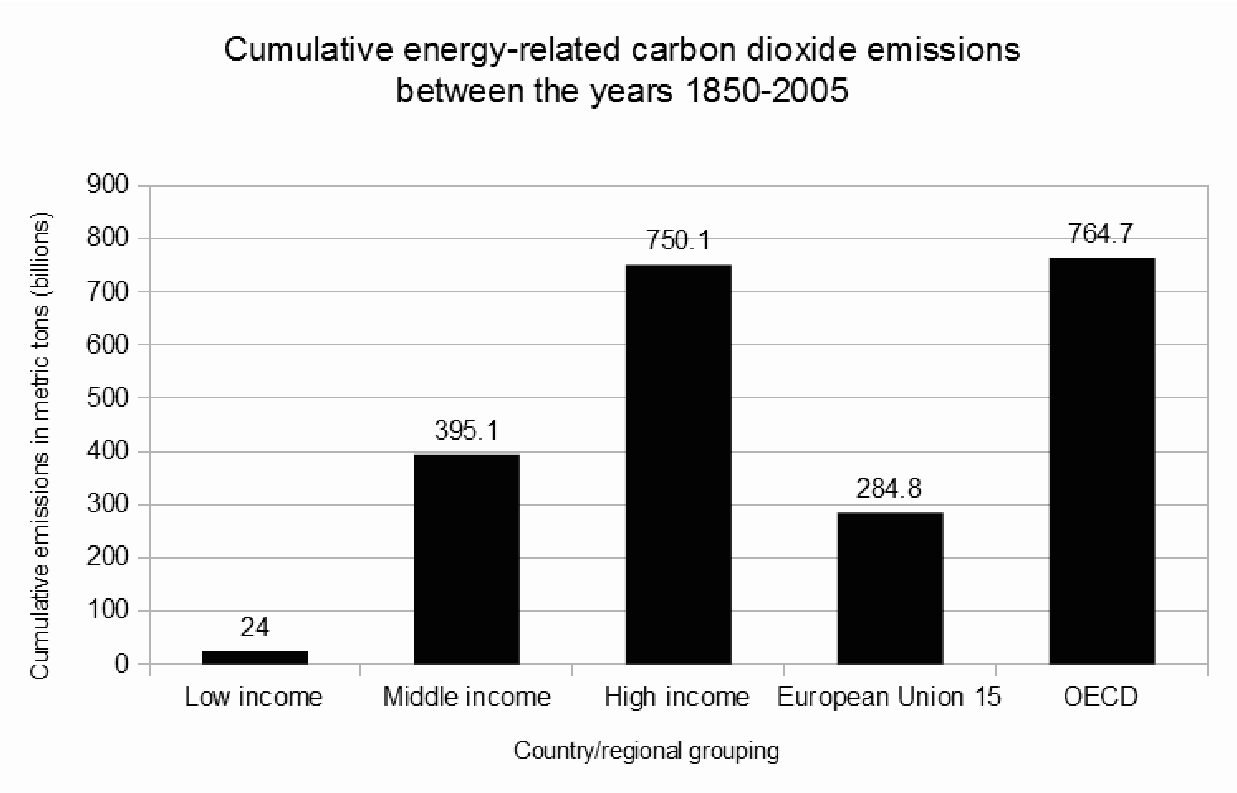


Figure 5: Cumulative Energy related CO_2 Emissions (18950-2005)



The above charts indicate that despite the historic responsibility of the developed nations for emitting the largest proportion of GHG, it is the now developing countries that are largely responsible for incremental emissions that are being emitted every day. This is especially true for large developing countries like India and China, who although are one of the biggest polluting countries, but have low per capita emissions, reflecting vast development needs of the country as a whole. This is the bone of contention between the developed and developing countries, i.e., who should pay up the cost of mitigation and adaptation to climate change: the ones with historic liability or the ones with current responsibility. It is therefore required to understand what is driving the GHG emissions in both sets of countries. In the course declaration of the respective 'Intended Nationally Determined Contributions' towards agreement to a new Climate Deal post the Kyoto Framework, various countries, both developing and developed have announced several intended emission reduction targets, including reduction of energy and carbon intensities of their economies. As large amount of finance is required to achieve such targets, it becomes imperative to identify the sectors that are to be targeted on priority.

This dissertation seeks to investigate the drivers of carbon emission intensity of two groups of countries- developed and developing, in order to understand the underlying dynamics of GHG emissions and therefore recommend suitable policy measures.

2. Review of Literature and Research Gap

2.1.Literature Review

(Dalei, 2015) in a research paper on open economies has shown that energy consumption has an S-shaped relationship with per capita GDP, Trade Openness and CO_2 emissions individually. Specifically for Carbon emissions, using panel data for India, Japan and China, it was shown that energy consumption increases with more emissions initially (due to reasons like greater use of cooling devices), with the rate of increase slowing down as the same rose beyond a threshold limit. This reflects a societal shift towards more efficient equipment.

(Alkhathlan & Javid, 2013) in a paper analysising data from Saudi Arabia at aggregate and disaggregate levels have demonstrated that carbon emissions increse monotonically with increase in per capita income at the aggrgate level and for oil and electricity conumption levels.

(Hossain, 2012) in his paper has examined the dynamic causal relationship between carbon emissions, energy consumption, economic growth, foreign trade and urbanisation in Japan. It was found that carbon emissions are positively affected by energy consumption and trade openness in the short run. It was observed that over long term, higher energy production would lead to higher levels of carbon emissions. Also in the long run, it was noted that environment quality would be a normal good.

(Bozkurt & Akan, 2014) in a research paper, attempted to investigate the long run effect of carbon emissions and energy use on economic growth in Turkey. Empirical verification of Turkish time series data using tools like co-integration, found that there was a unique long term relationship between GDP per capita, energy consumption and carbons emissions. While the former positively impacts per capita GDP, the latter impacts the same negatively.

(Omri, Daly, Rault, & Chaibi, 2015) in a paper, observed the relationship between variables like per capita income, carbon emissions, trade openness and financial development for Middle East and North African (MENA) countries. Using simultaneous equation models, bidirectional relationship between carbon emissions and economic growth was established along with the unidirectional relationship running from trade openness to carbon emissions. Also the existence of the Environmental Kuznets Curve for such countries was verified.

(Martínez-Zarzoso, 2008) in a project examining the relationship between carbon emissions and urbanization across low, lower middle income and upper middle income countries. It was observed that the emission-urbanization elasticity is higher than unity for low income countries while the same was measured at a level slightly less than unity. However for the most affluent group of countries, the elasticity was found to be negative. It could thus be inferred that upon reaching a certain threshold level, the effect of urbanization on emissions turn negative.

(Choi, Heshmati, & Cho, 2010) in a paper tested the presence of the Environmental Kuznets Curve for Japan, South Korea and China. Varying results for all three countries was obtained. While for Japan, U-shaped EKC was observed, an N-shaped EKC was obtained for China with a semi U-shaped curve for South Korea. For the relationship between per capita emissions and trade openness, inverted U and U-shaped curves were obtained for South Korea and China respectively and a monotonically curve for Japan was observed.

(Dalei, 2014) undertook a similar analysis in the context of India and found the existence ofa U-shaped EKC, though the possibility of N-shaped EKC was not completely ruled out.

(Raupach, 2007) in a paper undertook regionalized analysis of trends in emissions and their demographic, economic, and technological drivers, using the "Kaya Identity" and annual time-series data on national emissions, population, energy consumption, and GDP. The Kaya identity, establishes the relationship between the global emission flux, (F) and its four primary factors, i.e.global population (P), per capita World GDP (g), energy intensity of World GDP (e) and carbon intensity of energy (f). Symbolically,

$$F = Pgef$$

Nine noncontigous regions (U.S., EU, Japan, D1, i.e., other developed, Former Soviet Union, China, India, D2, i.e., other developing, and D3, i.e., least developed countries) were analysed for the purposes ofthis study. It was observed that growth in emissions since the year 2000 were driven by a cessation or reversal of earlier declining trends in the energy intensity of gross domestic product and the carbon intensity of energy, coupled with continuing increases in population and per-capita GDP. The growth rate in emissions was found to be strongest in rapidly developing economies, particularly China.

(The World Bank , 2009) in a report compared countries on their absolute levels of CO_2 emissions from energy use—more specifically, from the combustion of fossil fuels—as well as the levels of emissions per capita and per unit of gross domestic product (GDP). A decomposition technique, an accounting methodology based on a "Log Mean Divisia" index, was used to analyze the change in CO_2 emissions over a decade, i.e., 1994-96 to 2004-06. The methodology allowed the change in emissions to be separated into changes in five factors:

- The carbon intensity of fossil fuels consumed
- The share of fossil fuels in total energy used (fossil fuel intensity of energy)
- The energy required to produce a unit of GDP (energy intensity)
- GDP per capita
- Population

It was found that in about 80% of countries analyzed emission positively correlated with increases in population and per capita national income. In about two thirds of the countries analyzed, a fall in energy intensity of GDP was reported, while for more than half of the countries studied, fossil fuel intensity increased, reflecting declining usage of traditional biomass.

(Fan, 2006) in a paper investigated the reasons for reduction in the overall energy intensity of the Chinese economy between 1980 and 2003 using "Adaptive Weighted Divisia" index decomposition method, focussing upon primary energy related carbon intensity and the material sectors'(primary, secondary and tertiary sectors) final energy related carbon intensity . It was shown that decline in primary energy related carbon intensity was due decline in real energy intensities. The change in primary fuel mix, i.e., reduction in the share of coal in the fuel mix aided the fall in carbon intensity during this period. Also observed was the contribution of reduction in the energy intensity of the material sectors (majorly the industrial sector) along with reduced emissions from power generating stations in lowering the overall energy intensity of the economy.

(Fischer & Springborn, 2009) investigated the effectiveness of emission targets over caps or taxes using a "Real Business Cycle" model. Using a "Dynamic Stochastic General Equilibrium" framework, it was shown that while a policy of emission caps dampens the impact of productivity shocks to the economy, a policy of emission tax leads to same outcomes but with greater volatility.

A policy of certainty equivalent intensity targets on the other hand was shown to achieve higher levels of labor, capital, and output than other policies, with lower expected costs and no more volatility than with no policy.

(Pizer, 2005) discussed the usefulness of emission intensity target as a tool for reducing emissions. It was argued that with absolute targets emphasizing zero or declining emissions growth, it is difficult to enforce such measures especially upon developing countries, whose economic development is integrally tied to emissions growth for the foreseeable future. Therefore intensity targets that do not emphasize such reductions will be more acceptable and need not be any more complicated to administer than absolute targets.

(Gang, 2010) analyzed China's emission reduction policy in the light of Her commitment of reduction in emission intensity by 40% to 45% by 2020 at the UNFCC Summit COP 15 Copenhagen 2009. With China sticking to Her "Growth First" policy, it is predicted that She is likely to rely on intensity reduction targets as substitute for direct emission caps for alleviation of international pressures while simultaneously pursuing a greener development path in order to mitigate adverse effects of climate change.

From the above review of literature, one can conclude that the amount carbon emissions is positively correlated to economic growth, trade and FDI inflows. Several authors have made efforts to determine the precise relationship between the amount of emissions and the factors mentioned above. Of late it has been noted that targeting of emission intensity is a better option than targeting of absolute emission in course mitigation of global warming. This is especially true for developing countries, which contribute the highest amount of incremental pollution in the atmosphere but at the same time have valid developmental requirements. Therefore given the importance and prominence of carbon intensity targets at future climate change negotiations, as exemplified by China at COP 15, it is important to understand the drivers of the same, in context of both developed and developing nations.

2.2.Research Gap

The literature studied thus lacks a comprehensive study on the factors driving the carbon intensity of an economy. This dissertation aims to conduct such a study in the context of both the developed and developing economies. Such an analysis is likely to yield the areas that have the maximum possibility of being successfully targeted by appropriate policy measures, in order to achieve tangible benefits towards meeting of mitigation and adaption from climate change goals.

3. Research Objectives and Methodology

3.1. *Research Questions*:

1. What are the factors affecting carbon intensity in “Developed” countries?
2. What are the factors affecting carbon intensity in “Developing” countries?

3.2. *Research Objectives*:

1. To determine the factors driving carbon intensity in “Developed” countries.
2. To determine the factors driving carbon intensity in “Developing” countries.

3.3. Methodology

For the purposes of satisfaction of the above mentioned objectives, causal research design shall be followed.

Carbon intensity (ci) can be defined as: CO_2 emission/GDP (i.e., amount of CO_2 emitted per unit of GDP) expressed in terms of kilo tons (kt) per U.S. dollar.

Through the study of literature (WRI), the following variables are hypothesized to have a relationship with carbon intensity:

Energy intensity (ei) = Total Energy Consumption/GDP (i.e., amount of energy consumed per unit of GDP), expressed in terms of kilograms of oil equivalent (kgoe) per U.S. dollar.

Fuel mix (fi) = CO_2 emission/ Total Energy Consumption (i.e., proportion of carbon content in the overall amount of energy consumed), expressed in terms of kilo tons (kt) per kilograms of oil equivalent (kgoe).

To the above we add the Proportion of Urban Population (urb) = Population in Urban areas/Total Population

Mathematically:

C = f (ei, fi, urb)

For analysis a panel of five countries (each for developed and developing countries) will be considered with data for 30 years per country (1982-2011). Data for the above mentioned variables shall be collected from World Bank. Following Developed countries shall be considered:

1. The United States
2. Japan
3. Norway
4. France
5. The United Kingdom

These countries represent the five of the largest developed economies of the World and therefore have been chosen in this sample for the purposes of the study.

As for the developing countries, the following countries shall be considered:

1. India
2. China
3. Brazil
4. South Africa
5. Indonesia

These countries represent five of the largest developing economies of the World and therefore have been chosen in this sample for the purposes of the study.

For each set of countries, a panel regression will be conducted, which shall be followed up with an analysis of policy implications of the results obtained.

Specifically, three models shall be employed for the purposes of the study. Initially, a pooled OLS regression shall be run, taking into account the country specific dummy variable (to check for country specific variations in the model). This shall be followed up by implementing the 'Fixed Effects' linear model and the 'Random Effects' linear model. Results of the 'Hausman Test' shall determine the appropriateness of the models for both sets of the countries.

A limitation of this study arises out of the fact that models comprising time dummies have not been constructed due lack of time available at hand.

4. Data Analysis

4.1.Descriptive Analysis

The table below describes the major trends observed in the variables comprised in the models over the period of study. Logarithmic values for carbon intensity (ci), energy intensity (ei) and fossil fuel intensity (fi) have been used to depict the average growth rates for such variables across the five developed and developing countries under consideration.

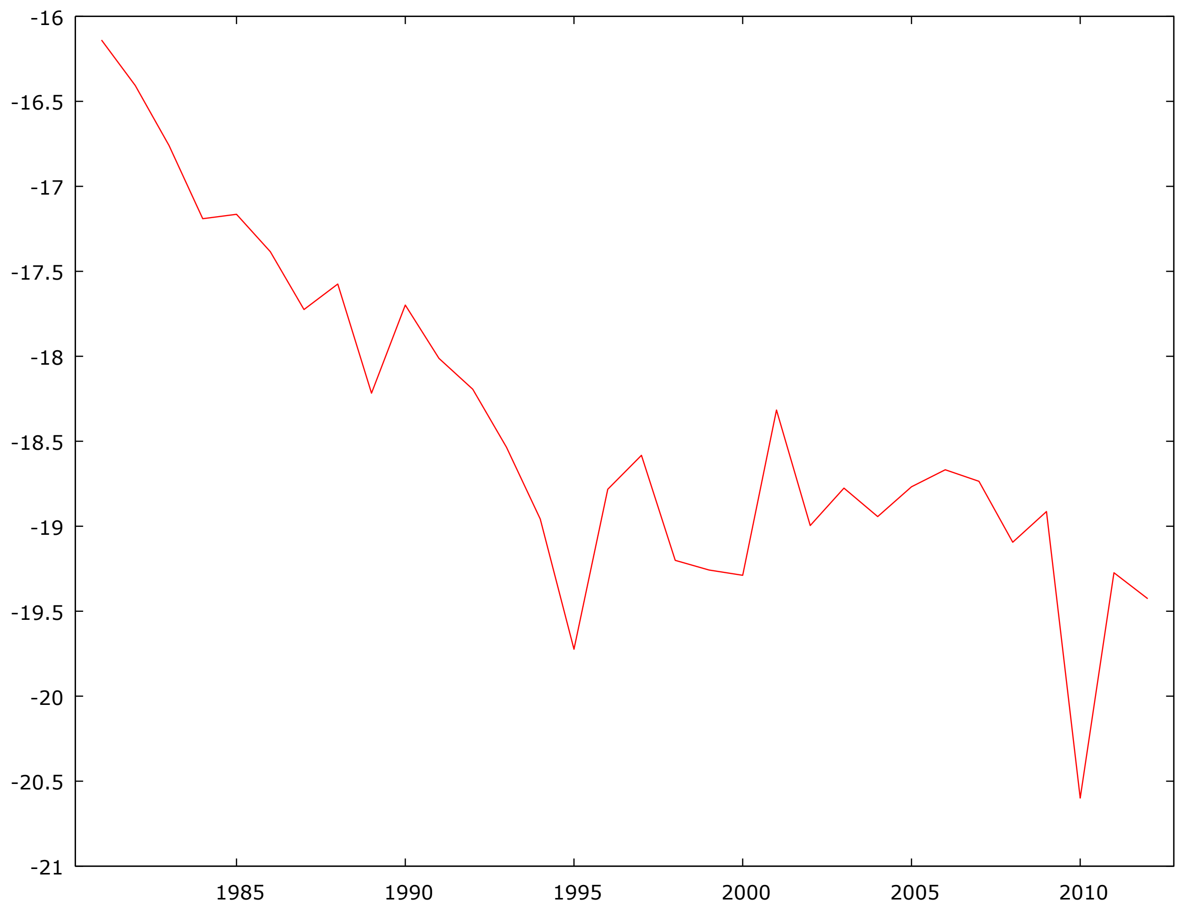
Variable	Mean		Std. Deviation		Min		Max	
	Dev	Devl	Dev	Devl	Dev	Devl	Dev	Devl
lci	(-) 18.3205	(-) 15.4736	1.253027	1.275122	(-) 22.7797	(-) 18.0867	(-) 15.4063	(-) 11.3132
lei	(-) 23.0872	-21.874	1.935619	1.963013	(-) 27.7207	(-) 26.2606	(-) 18.5115	(-) 16.7251
lfi	4.760392	6.440376	1.549755	1.299713	1.75191	4.568028	6.627074	8.407228
urbn	77.31661	45.60386	3.662782	19.51228	70.545	19.358	91.248	84.623

4.1.1. Carbon Intensity (ci)

Carbon intensity is expressed as kilo tons (kt) of 'Carbon Dioxide' emitted per U.S. dollar of GDP. The average growth rate of carbon intensity in developed nations is -18.3% while for developing countries the figure stands at -15.5%. Clearly the growth in carbon intensity in the developing countries is higher than that of the developed ones. The minimum and the maximum values for developed countries stood -22.8% and -15.4% respectively. The corresponding figures for developing countries are -18.9% and -11.3%.

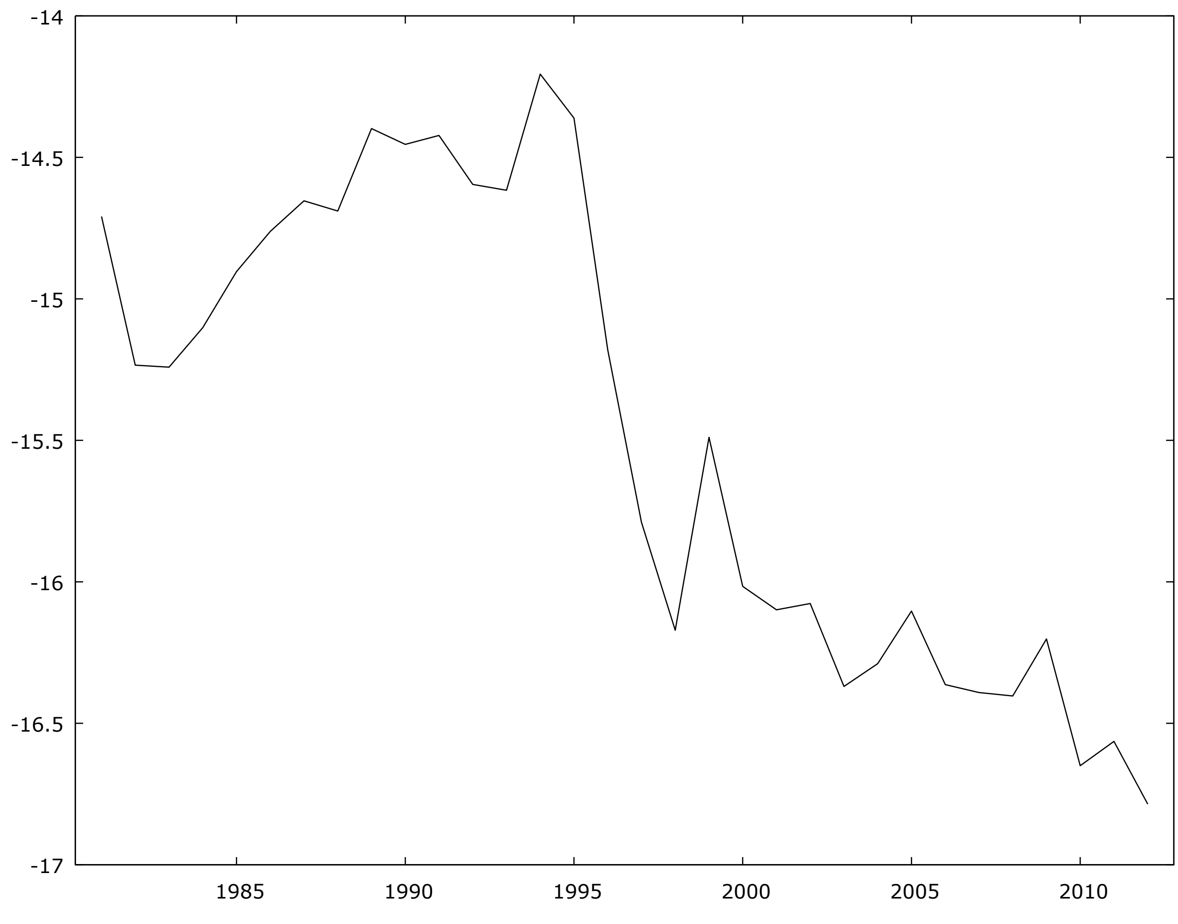
As figure 5 depicts, with the exception of few years, the growth rate of carbon intensity in the developed world has, in general, exhibited a declining trend. Adoption of fuel efficient and cleaner technologies for economic activities, post the oil shocks of the 1970s can be pin pointed as the major reason behind such a trend.

Figure 5: Growth in Carbon Intensity of Developed countries



The growth of carbon intensity in the developing countries also depict a similar trend. However, it can be observed from figure 6, that such nations have experienced significant spurts in the growth of carbon intensity from time to time. It can be discerned that such growth in carbon intensity coincides with the opening up of the 2 major economies of this group- India and China. While the latter initiated Her reform process in the early 1980s, the former began Her journey towards reforms in the early 1990s. It is therefore visibly clear that both these periods show significant acceleration in the generation of carbon intensity. A key enabler for the rapid adoption of clean technologies by the developed economies during the period under study was their financial strength and technological superiority, something that the developing countries did not enjoy.

Figure 6: Growth in Carbon Intensity of Developing countries



4.1.2. Energy Intensity (ei)

Energy intensity is expressed as kilograms of oil equivalent of energy consumed per U.S. dollar of GDP. The average growth rate of energy intensity in developed nations is -23.9% while for developing countries the figure stands at -21.9%. Clearly the growth in energy intensity in the developing countries is higher than that of the developed ones. The minimum and the maximum values for developed countries stood -27.7% and -18.5% respectively. The corresponding figures for developing countries are -26.3% and -16.7%.

On the whole, the growth rate of energy intensity in both the sets of countries show a declining trend. Figures 7 and 8 depict periods of simultaneous jumps and declines in the energy intensity in the two sets of economies. It can however be observed that the increments in the energy intensity is more in case of the developed nations as compared to the developing ones. Since early 2000s, it is detected that the energy intensity in the developed nations has actually outpaced the energy intensity observed on the developing countries.

The growth rate of energy intensity is statistically correlated (positive) with the growth rate of carbon intensity in case of both developed and developing countries. While the relevant correlation coefficient for developed countries was found to be 0.61, the same was found to be 0.76 for developing countries indicating a higher correlation among the variables in case of developing countries. From corresponding figures in this section and the ones in the previous section, it can be observed that the energy intensity carbon intensity follow the same pattern in both sets of countries. The figures also indicate that, towards the end of the period under study, the energy intensity and the carbon intensity is on the rise in developed countries, with the reverse being true for the developed ones. Given the fact that the U.S. is the largest economy in the given set of developed countries, discovery of shale resources and its impact on Her economy may have had the single biggest influence on the overall energy intensity and therefore carbon intensity of the developed countries taken as a whole. In case of developing countries, on the other hand, enhanced utilization of efficient and clean technologies, development of service industries (that are less energy intensive in nature) along with economic slowdown over the last few years are the potential causes for the persistent declines observed in the energy and carbon intensities.

Figure 7: Growth in Energy Intensity of Developed countries

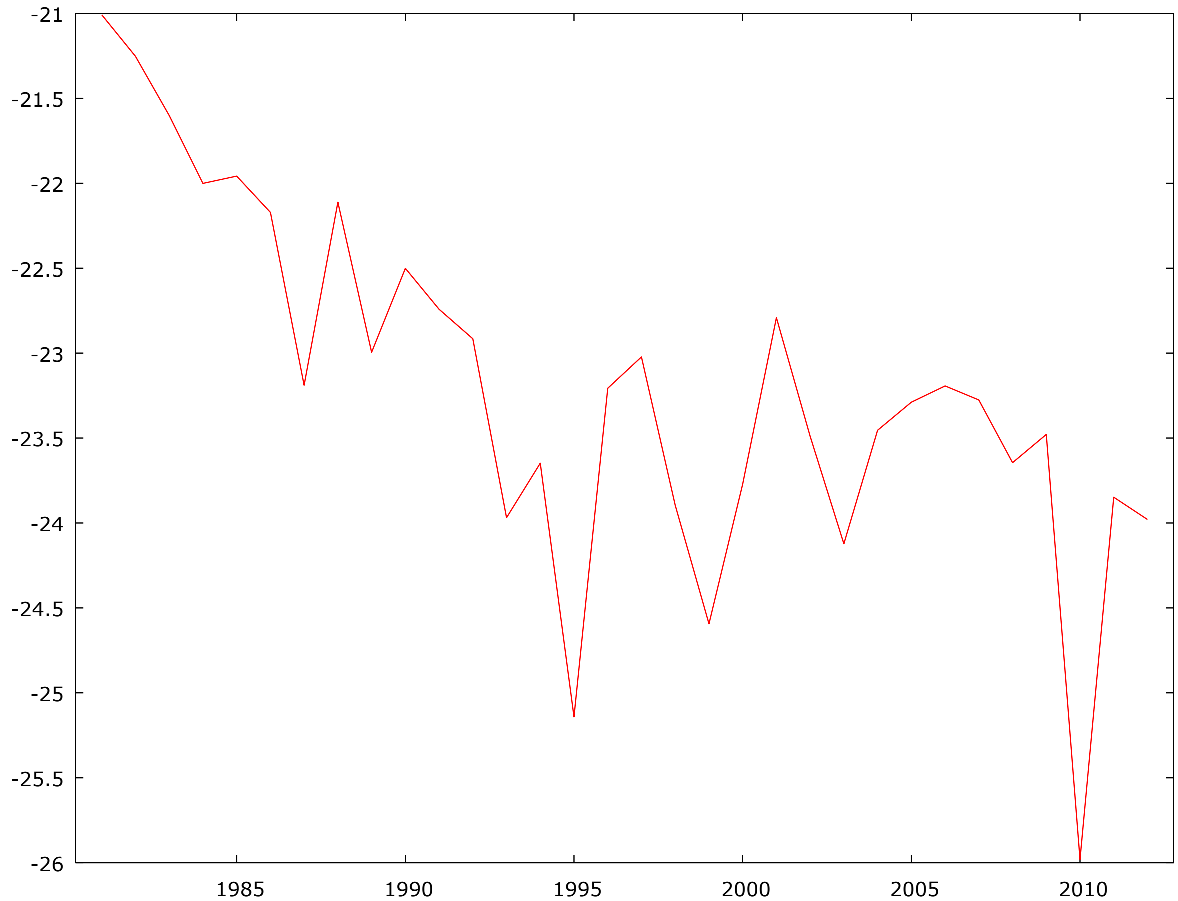


Figure 8: Growth in Energy Intensity of Developing countries

4.1.3. Fossil fuel intensity (fi)

Fossil fuel intensity is expressed as kilotons (kt) of 'Carbon Dioxide' emissions per kilogram (kg) of energy consumed. The average growth rate of fossil fuel intensity in developed nations is 4.76% while for developing countries the figure stands at 6.4%. Clearly the growth in fossil fuel intensity in the developing countries is higher than that of the developed ones. The minimum and the maximum values for developed countries stood 1.75% and 6.62% respectively. The corresponding figures for developing countries are 4.56% and 8.4%.

High and persistent fossil fuel intensity growth in developing countries, as depicted by figure 10, can be explained by their thrust towards rapid economic growth via escalated use of fossil fuels. The case of developed countries is however a little complicated. Figure 9 depicts a U- Shaped pattern in fossil fuel intensity growth. After falling continuously since the late 1980s, the fossil fuel intensity grows sharply after 1997-98. This is consistent with the observations made earlier about carbon intensity and energy intensity, which depict a similar trend post 1997-98. Therefore, it can be discerned that enhanced usage of energy was driven by fossil fuels, which ultimately resulted in the achievement of higher growth rates of carbon intensity levels in the developed countries.

Figure 9: Growth in Fossil fuel intensity of Developed countries

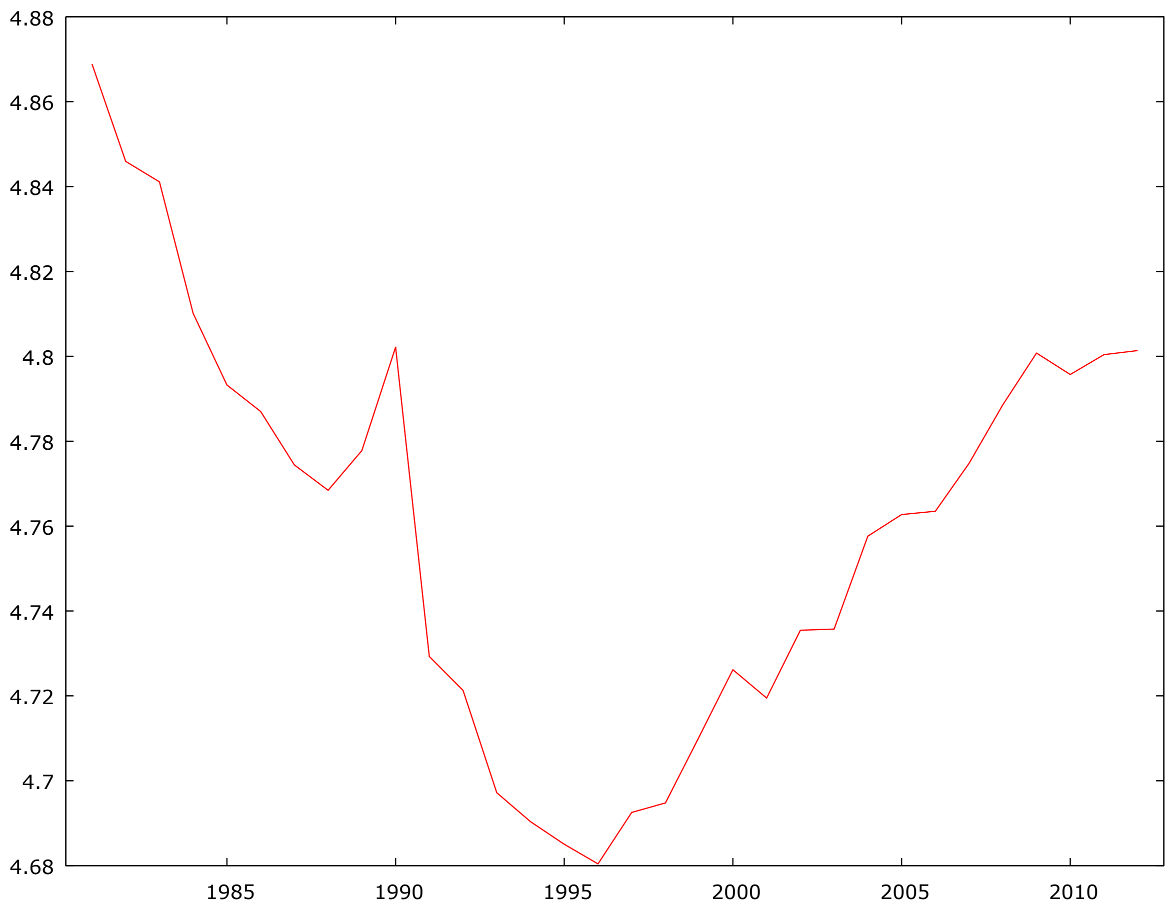
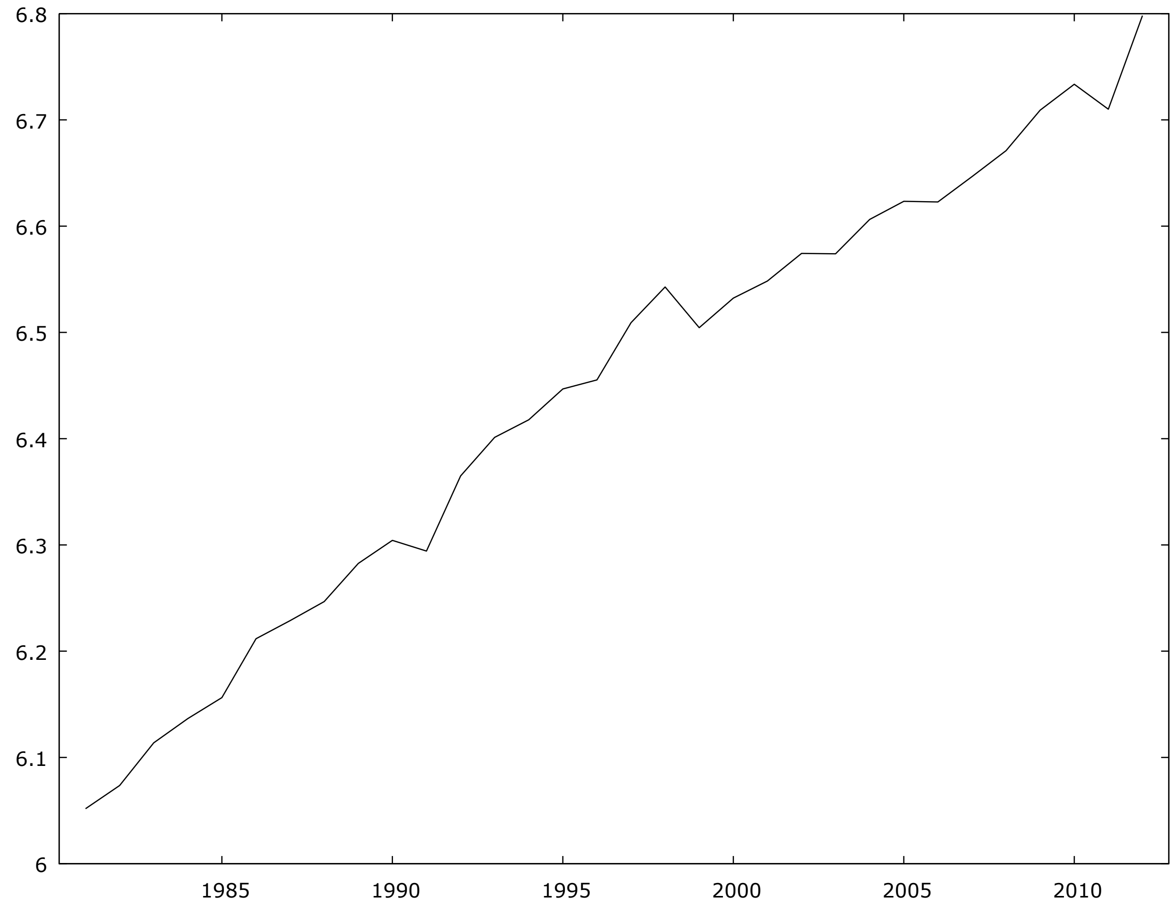


Figure 10 : Growth in Fossil fuel intensity of Developing countries



4.1.4. Proportion of Urban Population (urb)

The proportion of urban population in developed nations is 77.3% while for developing countries the figure stands at 45.6%. Clearly the proportion of urban population in developed countries is higher than that of the developing countries. The level of urbanization has increased in both the sets of countries, during the period of study. This is depicted by figures 11 and 12. The minimum and the maximum values for developed countries stood -70.5% and 91.2% respectively. The corresponding figures for developing countries are 19.3% and 84.6%.

Figure 11: Proportion of Urban Population in Developed countries

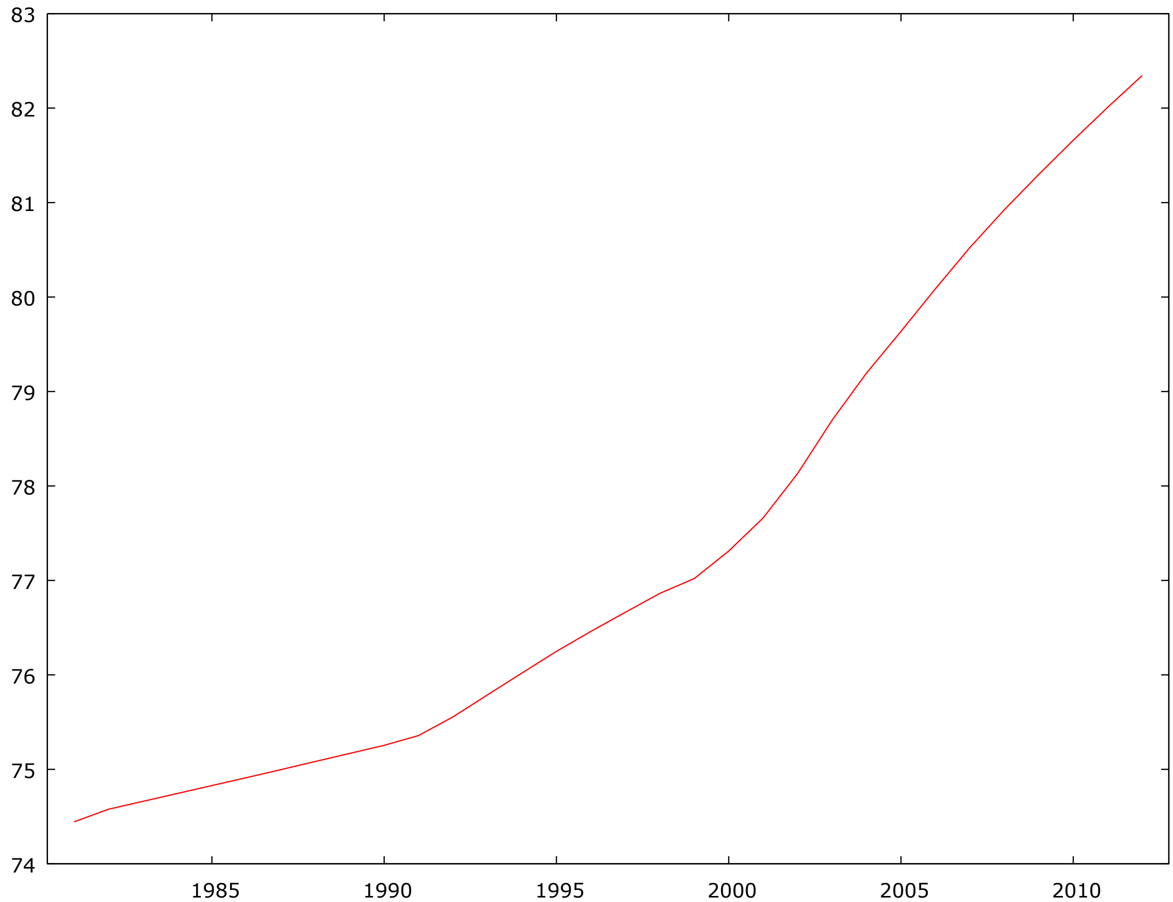
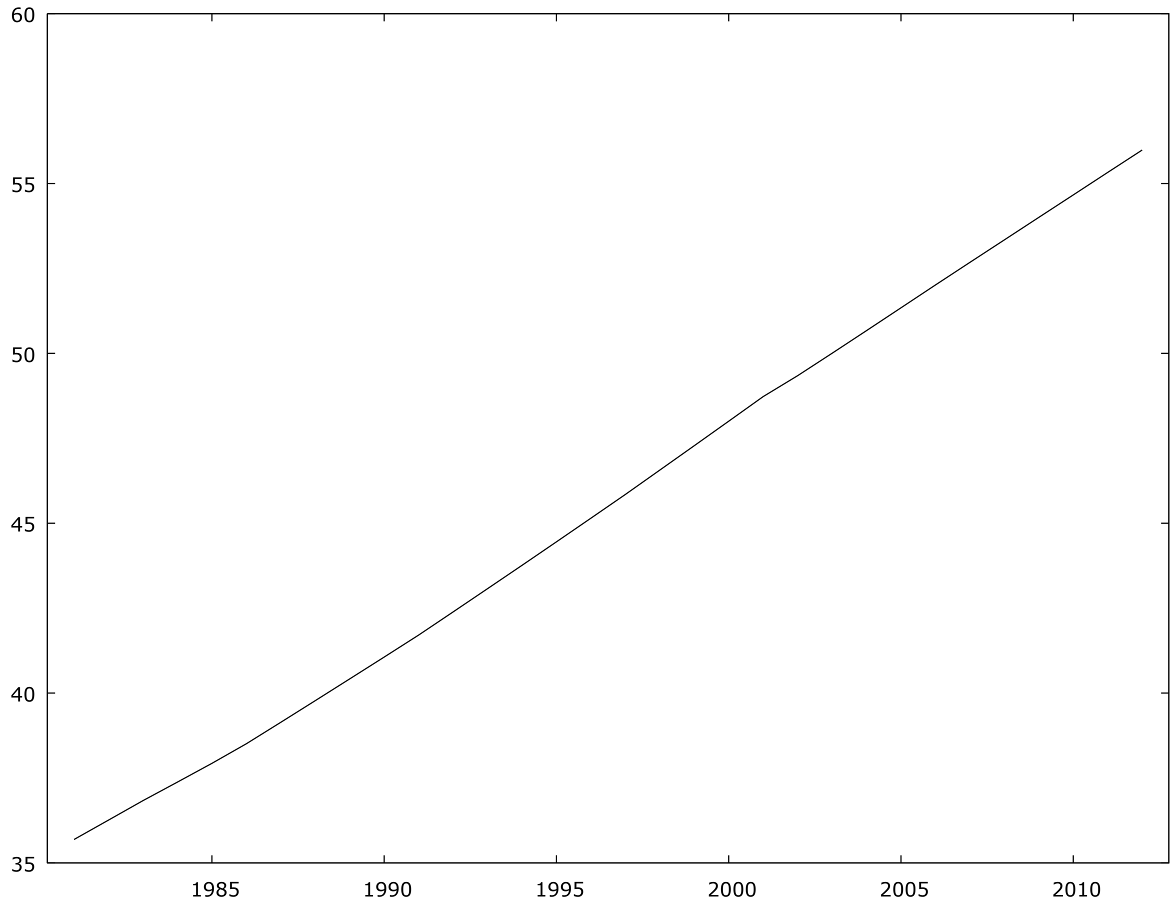


Figure 12: Proportion of Urban Population in Developing countries



4.2.*Panel Unit Root Tests*:

Panel unit root tests are necessary to ascertain whether the data under consideration is stationary w.r.t. time or not. Stationarity implies that the given data is time invariant, i.e., the same has constant mean and constant variance with the covariance between two time periods depends only on the distance between the two periods. If the underlying data is not stationary, it is likely that the results of the regression obtained will be spurious. Therefore, before proceeding with the core panel regression analysis, unit root tests are to be conducted. Levin Lin Chu test is used for verifying the stationarity of the variables under study. The test is conducted for both the sets of countries. If any variable is found to be non-stationary, appropriate transformation shall be carried out for converting the same into a stationary variable.

4.2.1. Carbon Intensity

Levin-Lin-Chu unit-root test for ci:

Ho: Panels contain unit roots Number of panels = 5

Ha: Panels are stationary Number of periods = 32

AR parameter: Common Asymptotics: N/T -> 0

Panel means: Include

Time trend: Included

ADF regressions: 1 lag

LR variance: Bartlett kernel, 10.00 lags average (chosen by LLC)

Developed Countries

t ratio	Statistic	p-value
Unadjusted t	(-) 11.2637	
Adjusted t*	-7.0938	0.000

Developing Countries

t ratio	Statistic	p-value
Unadjusted t	-6.2915	
Adjusted t*	-2.1278	0.0167

The variable was found to be stationary in case of both developed (at 1% level of significance) and developing countries (at 5% level of significance).

4.2.2. Energy Intensity

Levin-Lin-Chu unit-root test for ei

Ho: Panels contain unit roots   Number of panels = 5

Ha: Panels are stationary   Number of periods = 32

AR parameter: Common   Asymptotics: N/T -> 0

Panel means: Included

Time trend: Included

ADF regressions: 1 lag

LR variance: Bartlett kernel, 10.00 lags average (chosen by LLC)

Developed Countries

t Ratio	Statistic	p-value
Unadjusted t	-7.4239	
Adjusted t*	-2.1095	0.0175

Developing Countries

t Ratio	Statistic	p-value	

Unadjusted t	-7.0384		
Adjusted t*	-2.4712	0.0067	

The variable was found to be stationary in case of both developed (at 5% level of significance) and developing countries (at 5% level of significance).

4.2.3. Fossil fuel intensity

Levin-Lin-Chu unit-root test for fi

Ho: Panels contain unit roots Number of panels = 5

Ha: Panels are stationary Number of periods = 32

AR parameter: Common Asymptotics: N/T -> 0

Panel means: Included

Time trend: Included

ADF regressions: 1 lag

LR variance: Bartlett kernel, 10.00 lags average (chosen by LLC)

Developed Countries

t Ratio	Statistic	p-value
Unadjusted t	-4.0585	

Adjusted t*	-0.7967	0.2128

Developing Countries

t Ratio	Statistic	p-value
Unadjusted t	-4.5424	
Adjusted t*	-0.1548	0.4385

The variable was found to be non-stationary in case of both developed and developing countries. First difference of this variable (which was very to be stationary for both developed and developing countries) shall be used for further analysis.

4.2.4. Urban Population

Levin-Lin-Chu unit-root test for urbn

Ho: Panels contain unit roots Number of panels = 5

Ha: Panels are stationary Number of periods = 32

AR parameter: Common Asymptotics: N/T -> 0

Panel means: Included

Time trend: Included

ADF regressions: 1 lag

LR variance: Bartlett kernel, 10.00 lags average (chosen by LLC)

Developed Countries

t Ratio	Statistic	p-value
Unadjusted t	-4.6199	
Adjusted t*	-2.7914	0.0026

Developing Countries

t Ratio	Statistic	p-value
Unadjusted t	-3.2542	
Adjusted t*	-1.1393	0.1273

The variable was found to be stationary in case developed countries (at 5% level of significance). However in case of developing countries the same was found to be non-stationary. First difference of this variable (found to be stationary) shall be employed for further analysis.

4.3.Panel Data Analysis

Post stationarity checks, the final specification of the model being used is

Developed Countries:

$ci_{ut} = \beta_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ urb_{it} + u_{it}$

Developing Countries:

$ci_{ut} = \beta_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ d\_\ urb_{it} + u_{it}$

Where,

ci_{it} = Carbon Intensity of GDP

ei_{it} = Energy Intensity of GDP

fi_{it} = First difference of variable Fossil fuel intensity of Total Energy Use

urb: Proportion of Urban Population

d_urb: First difference of variable Proportion of Urban Population

u_{it} = Random Error term

For each of the two sets of countries, pooled OLS model, fixed effects model and random effects model is estimated.

4.3.1. Pooled OLS

In the pooled OLS model, country specific dummies are incorporated in order to account for country specific differences in the overall model. The following equation is estimated,

Developed Countries

$ci_{it} = \alpha_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ urb_{it} + \alpha_2\ djpn_i + \alpha_3\ dnor_i + \alpha_4\ dfra_i + \alpha_5\ duk_i + u_{it}$

Where,

dus: Country dummy for US

djpn: Country dummy for Japan

dnor: Country dummy for Norway

dfra: Country dummy for France

duk: Country dummy for UK

Developing Countries

$ci_{it} = \alpha_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ d\_urb_{it} + \alpha_2\ dchn_i + \alpha_3\ dbrz_i + \alpha_4\ drsa_i + \alpha_5\ dindo_i + u_{it}$

Where,

dind: Country dummy for India

dchn: Country dummy for China

dbrz: Country dummy for Brazil

drsa: Country dummy for South Africa

dindo: Country dummy for Indonesia

In case of estimation of fixed effects model, a specification without interaction dummy variables and with interaction dummy variables is implemented. Interaction dummy variables are used for identifying variables having significant country specific impact. The following equations are estimated,

4.3.2. Basic Fixed Effects Model

Developed Countries:

$ci_{it} = \beta_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ urb_{it} + u_{it}$

Developing Countries

$ci_{it} = \beta_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ d\_urb_{it} + u_{it}$

4.3.3. Fixed Effects with Interaction Dummies

Developed Countries

$ci_{it} = \alpha_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ urb_{it} + \alpha_2\ djpn_i + \alpha_3\ dnor_i + \alpha_4\ dfra_i + \alpha_5\ duk_i + \lambda_1\ (djpn_i{*}ei_{it}) + \lambda_2\ (djpn_i{*}\ d\_fi_{it}) + \lambda_3\ (djpn_i{*}urb_{it}) + \lambda_4\ (dnor_i{*}ei_{it}) + \lambda_5\ (dnor_i{*}\ d\_fi_{it}) + \lambda_6\ (dnor_i{*}\ urb_{it}) + \lambda_7\ (dfra_i{*}ei_{it}) + \lambda_8\ (dfra_i{*}\ d\_fi_{it}) + \lambda_9\ (dfra_i{*}urb_{it}) + \lambda_{10}\ (duk_i{*}ei_{it}) + \lambda_{11}\ (duk_i{*}\ d\_fi_{it}) + \lambda_{12}\ (duk_i{*}urb_{it}) + u_{it}$

Developing Countries

$ci_{it} = \alpha_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ d\_urb_{it} + \alpha_2\ dchn_i + \alpha_3\ dbrz_i + \alpha_4\ drsa_i + \alpha_5\ dindo_i + \lambda_1\ (dchn_i{*}ei_{it}) + \lambda_2\ (dchn_i{*}\ d\_fi_{it}) + \lambda_3\ (dchn_i{*}d\_urb_{it}) + \lambda_4\ (dbrz_i{*}ei_{it}) + \lambda_5\ (dbrz_i{*}\ d\_fi_{it}) + \lambda_6\ (dbrz_i{*}\ d\_urb_{it}) + \lambda_7\ (drsa_i{*}ei_{it}) + \lambda_8\ (drsa_i{*}\ d\_fi_{it}) + \lambda_9\ (drsa_i{*}d\_urb_{it}) + \lambda_{10}\ (dindo_i{*}ei_{it}) + \lambda_{11}\ (dindo_i{*}\ d\_fi_{it}) + \lambda_{12}\ (dindo_i{*}d\_urb_{it}) + u_{it}$

Finally a random effects or error components model is constructed

4.3.4. Random Effects Model

Developed Countries

$ci_{it} = \beta_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ urb_{it} + \omega_{it}$

Developing Countries

$ci_{it} = \beta_1 + \beta_2\ ei_{it} + \beta_3\ d\_fi_{it} + \beta_4\ d\_urb_{it} + \omega_{it}$

Where $\omega_{it} = \varepsilon_{it} + u_{it}$; ε_{it} = random error term of the function $\beta_{1i} = \beta_1 + \varepsilon_{it}$

Note: $\beta_1, \beta_2, \beta_3$ & β_4 – Independent variable slope coefficients
$\alpha_1, \alpha_2, \alpha_3, \alpha_4,$ & α_5 – Dummy coefficients
$\lambda_1, \lambda_2, \lambda_3 \ldots\ldots\ldots \lambda_{12}$ – interaction dummy coefficients

5. Results and Discussion

5.1.*Developed Countries*:

Model 5.1.1: Heteroskedasticity-corrected, using 155 observations

Dependent variable: ci

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1.30658e-07	2.45491e-08	5.3223	<0.0001	***
ei	7.11379	0.892564	7.9701	<0.0001	***
d_fi	−4.52615e-010	2.4332e-010	−1.8602	0.0649	*
urbn	−1.37782e-09	3.20497e-010	−4.2990	<0.0001	***
djpn	−1.85965e-08	2.8192e-09	−6.5964	<0.0001	***
dnor	−2.71205e-08	3.08166e-09	−8.8006	<0.0001	***
dfra	−1.7766e-08	4.27157e-09	−4.1591	<0.0001	***
duk	9.80536e-010	6.60024e-09	0.1486	0.8821	

Significance: *** (1%) ** (5%) * (10%)

Statistics based on the weighted data:

Sum squared resid	596.5102		S.E. of regression	2.014421
R-squared	0.543915		Adjusted R-squared	0.522196
F(7, 147)	25.04401		P-value(F)	2.89e-22
Log-likelihood	−324.3800		Akaike criterion	664.7600
Schwarz criterion	689.1074		Hannan-Quinn	674.6493

Statistics based on the original data:

Mean dependent var	1.59e-08		S.D. dependent var	2.34e-08
Sum squared resid	5.31e-14		S.E. of regression	1.90e-08

The pooled OLS estimates indicate that energy intensity (at 1% level of significance), has a positive impact on carbon intensity. Specifically a unit increase in energy intensity will increase the carbon intensity of the developed nations by 7.1 kt/ unit of GDP. Fossil fuel intensity as a factor (at 10% level of significance) has been found to have a negative impact, at 10% level of significance, with carbon intensity falling by 0.0000004 kt/ unit of GDP with every unit increase in the same. Also with every 1% increase in the proportion of urban population in developed nations, it is observed that carbon intensity declines by 0.0000000013 kt/ unit of GDP (at 1% level of significance) Also observed is the significance of individual country dummies in case of Japan, Norway and France (significant at 1% level). This implies that the intercepts of the respective functions of the individual countries is different from that of US (the base country).

Model 5.1.2. : Fixed-effects, using 160 observations
Included 5 cross-sectional units
Time-series length = 32
Dependent variable: ci
Robust (HAC) standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	7.89251e-08	7.41681e-08	1.0641	0.2890	
ei	4.30057	1.10012	3.9092	0.0001	***
d_fi	−1.10776e-09	2.11323e-010	−5.2420	<0.0001	***
urbn	2.92535e-010	1.00879e-09	0.2900	0.7722	

Mean dependent var	1.89e-08		S.D. dependent var	3.02e-08
Sum squared resid	5.49e-14		S.E. of regression	1.90e-08
LSDV R-squared	0.620934		Within R-squared	0.578163
LSDV F(7, 152)	35.56939		P-value(F)	4.77e-29

Log-likelihood	2621.594		Akaike criterion	−5227.188
Schwarz criterion	−5202.586		Hannan-Quinn	−5217.198
rho	0.574545		Durbin-Watson	0.541557

Significance: *** (1%) ** (5%) * (10%)

Joint test on named regressors -

Test statistic: F (3, 152) = 69.4428

With p-value = P (F (3, 152) > 69.4428) = 2.44954e-028

In the basic fixed effects model, energy intensity is found to have a positive impact on carbon intensity at 1 % level of significance, with the latter rising by 4.3 kt/ unit of GDP for every unit increase in the former. Also fossil fuel intensity is found to have a negative relationship with carbon intensity, (at 1% level of significance), with the latter declining by 0.00000011 kt/ unit of GDP with every unit rise in the former. Proportion of urban population though has a positive relationship with carbon intensity, has not been found as a statistically significant variable impacting the same.

Model 5.1.3. : Fixed-effects, using 155 observations

Included 5 cross-sectional units

Time-series length = 31

Dependent variable: ci

Robust (HAC) standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−1.55379e-08	7.90661e-09	−1.9652	0.0514	*
ei	588.856	0.538522	1093.4666	<0.0001	***
d_fi	3.66905e-012	4.40212e-011	0.0833	0.9337	
urbn	8.98542e-011	1.56908e-010	0.5727	0.5678	

$djpn_i*ei_{it}$	−271.774	7.78872	−34.8932	<0.0001	***
$djpn_i*$ d_fi_{it}	−1.74304e-012	1.47287e-012	−1.1834	0.2387	
$djpn_i*urb_{it}$	−8.37903e-011	1.06375e-010	−0.7877	0.4323	
$dnor_i*ei_{it}$	−581.187	0.514936	−1128.6583	<0.0001	***
$dnor_i*$ d_fi_{it}	9.13347e-010	3.54777e-012	257.4428	<0.0001	***
$dnor_i*$ urb_{it}	−1.47477e-010	3.05446e-011	−4.8283	<0.0001	***
$dfra_i*ei_{it}$	−453.142	0.139236	−3254.4984	<0.0001	***
$dfra_i*$ d_fi_{it}	1.58981e-010	5.15511e-012	30.8395	<0.0001	***
$dfra_i*urb_{it}$	4.339e-010	4.56111e-011	9.5130	<0.0001	***
duk_i*ei_{it}	−424.443	0.811565	−522.9934	<0.0001	***
duk_i* d_fi_{it}	1.00607e-010	1.00535e-011	10.0072	<0.0001	***
duk_i*urb_{it}	3.05091e-010	5.05982e-011	6.0297	<0.0001	***

Mean dependent var	1.59e-08		S.D. dependent var	2.34e-08
Sum squared resid	1.68e-16		S.E. of regression	1.11e-09
LSDV R-squared	0.998008		Within R-squared	0.997726
LSDV F(19, 135)	3560.641		P-value(F)	2.6e-172
Log-likelihood	2986.049		Akaike criterion	−5932.099
Schwarz criterion	−5871.230		Hannan-Quinn	−5907.375
rho	0.404832		Durbin-Watson	1.019903

Significance: *** (1%) ** (5%) * (10%)

Joint test on named regressors -

Test statistic: F (15, 135) = 3948.89

With p-value = P (F (15, 135) > 3948.89) = 2.21937e-170

F-Test (12, 144) = 2.52 (significant at 1% level of significance)

In the fixed effects model with interaction dummies, although the relationship between carbon intensity and energy intensity still holds as mentioned above, the relationship between carbon intensity and fossil fuel intensity breaks down. The latter has been found to have a positive relationship with the former in this model, though the same is statistically insignificant. Observation of the interaction dummies throw interesting light over the differences in the independent variables across the developed. Energy intensity, observed in all other countries is found to be significantly different from the levels observed in the base country, i.e., the US. In general it is observed that the impact of energy intensity on carbon intensity in all other developed countries considered in this study is less than that of the US (base country). The difference observed is least in case of Norway (7 kgoe/ unit of GDP) and most in case of Japan (310 kgoe/ unit of GDP). The impact of energy intensity of France is found to be more than that of UK. Also found is the variation in the impact of urbanization on carbon intensity with respect to the figure for the base, in case of Norway, France and U.K. The impact varies by -0.00000000014 kt/ unit of GDP in case of Norway, 0.00000000043 kt/ unit of GDP in case of France and -0.0000000003 kt/ unit of GDP in U.K. The significant of the F-statistic reveals that the model with interaction dummies is more robust and is better suited for further analysis.

Model 5.1.4. : Random-effects (GLS), using 160 observations

Included 5 cross-sectional units

Time-series length = 32

Dependent variable: ci

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1.12528e-07	4.75247e-08	2.3678	0.0191	**
ei	5.1507	1.50032	3.4331	0.0008	***
d_fi	−8.69916e-010	9.66804e-011	−8.9978	<0.0001	***
urbn	−3.83209e-	6.33126e-010	−0.6053	0.5459	

	010				

Mean dependent var	1.89e-08		S.D. dependent var	3.02e-08
Sum squared resid	3.26e-13		S.E. of regression	4.56e-08
Log-likelihood	2479.134		Akaike criterion	−4950.269
Schwarz criterion	−4937.968		Hannan-Quinn	−4945.274

Significance: *** (1%) ** (5%) * (10%)

'Within' variance = 3.61415e-016

'Between' variance = 3.65317e-016

Theta used for quasi-demeaning = 0.82417

Breusch-Pagan test -

Null hypothesis: Variance of the unit-specific error = 0

Asymptotic test statistic: Chi-square (1) = 93.2111

With p-value = 4.70036e-022

Hausman test -

Null hypothesis: GLS estimates are consistent

Asymptotic test statistic: Chi-square (3) = 28.7706

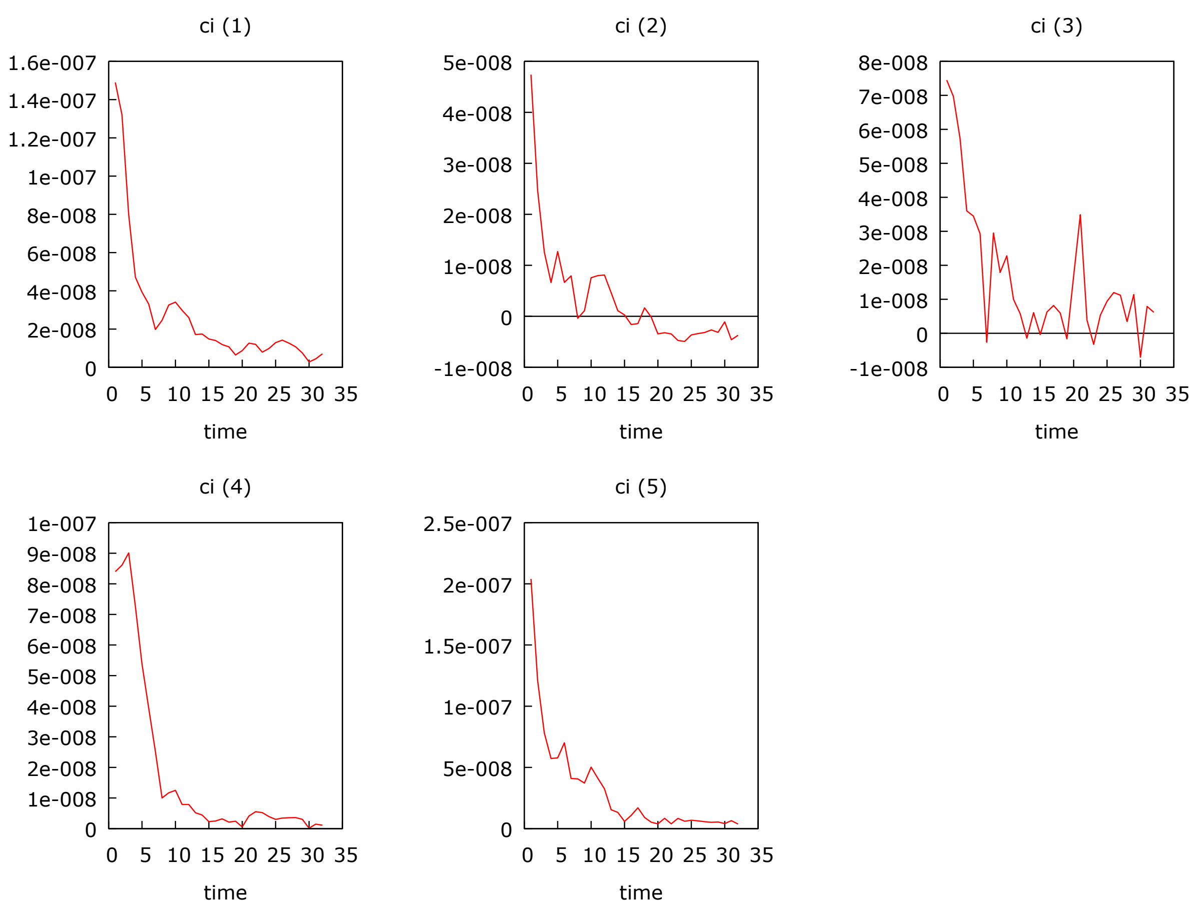
With p-value = 2.50227e-006

As per the random effects model, energy intensity and fossil fuel intensity are the statistically significant variables. While energy intensity leads to a 5. 1 kt/ unit of GDP increase in carbon intensity, fossil fuel intensity leads to a Decline in the same by 0.0000000008 kt/ unit of GDP. The results of the Hausman test (with the value of Chi square statistic less than 0.05) indicate that the fixed effects model constructed above is more valid and should be used for drawing policy conclusions.

Figure 14 depicts the respective energy intensity and figure 13 depicts the carbon intensity of the developed countries considered in this study. It is clearly visible that the two variables follow a similar pattern, corroborating the results of the regression. High level of economic activity in such countries utilizes significant amounts of energy.

Although the fixed effects model, taking into account the interaction dummies, one finds that energy intensity has the major impact on the carbon intensity of the developed economies, it would be useful to study the impact of fossil fuel intensity.

Figure 13: Carbon Intensity (Dev)



Note:

1 – US

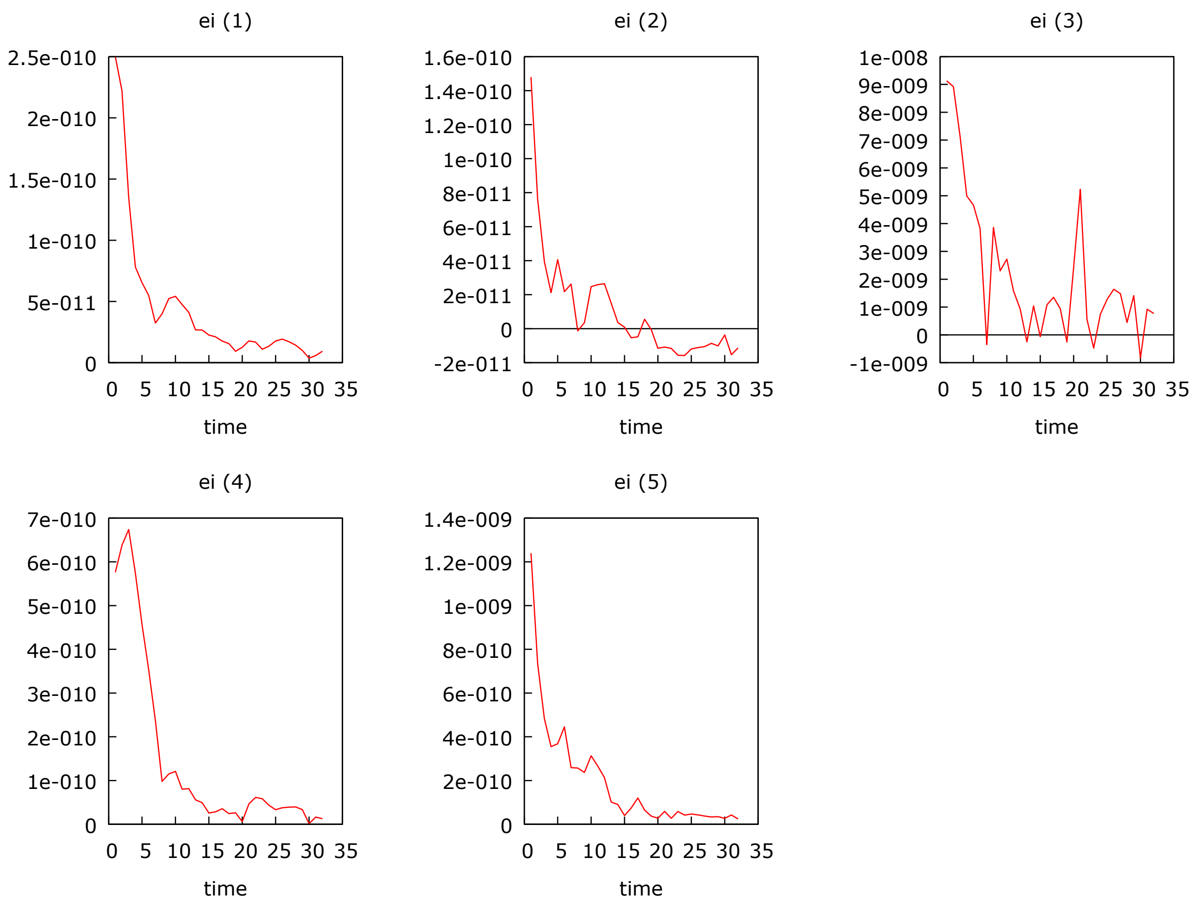
2- Japan

3- Norway

4- France

5- UK

Figure 14: Energy Intensity (Dev)



Note:

1 – US

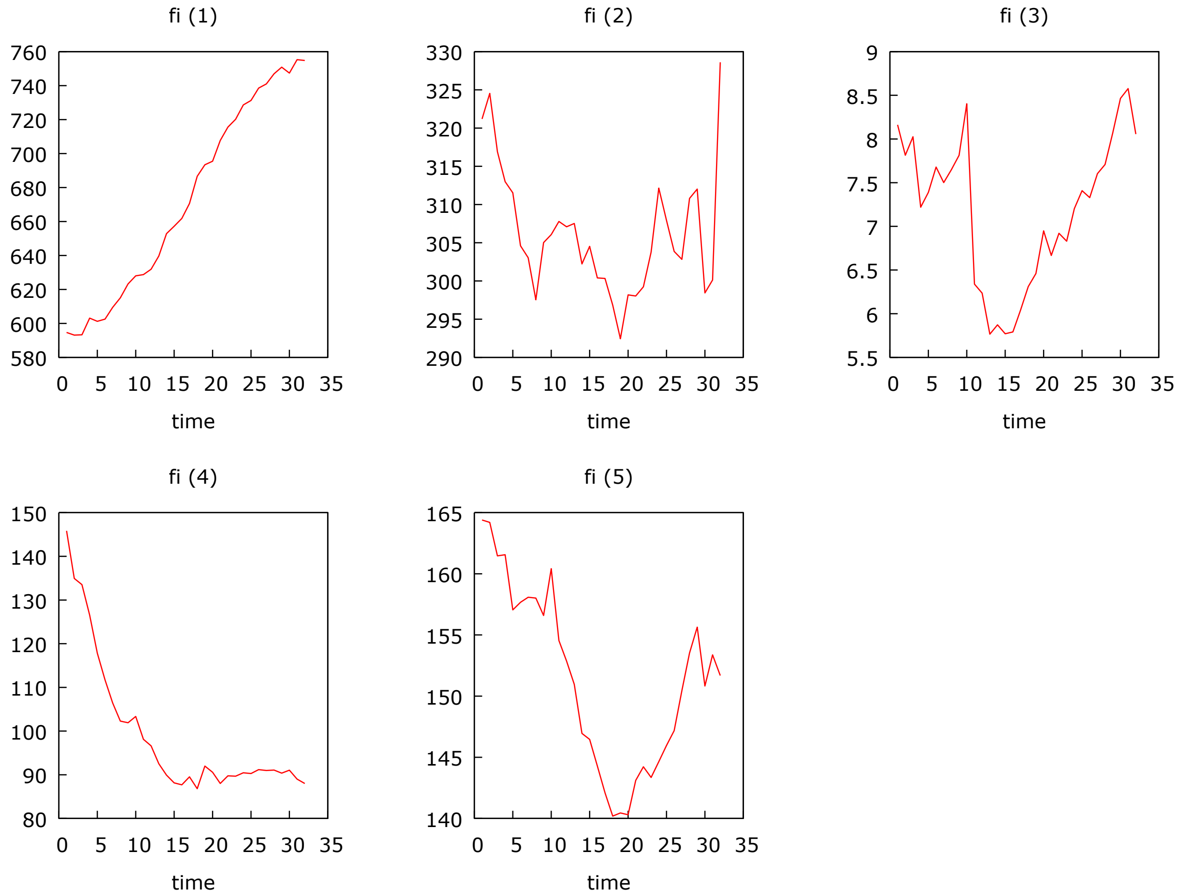
2- Japan

3- Norway

4- France

5- UK

Figure 15: Fossil fuel intensity (Dev)



Note:

1 – US

2- Japan

3- Norway

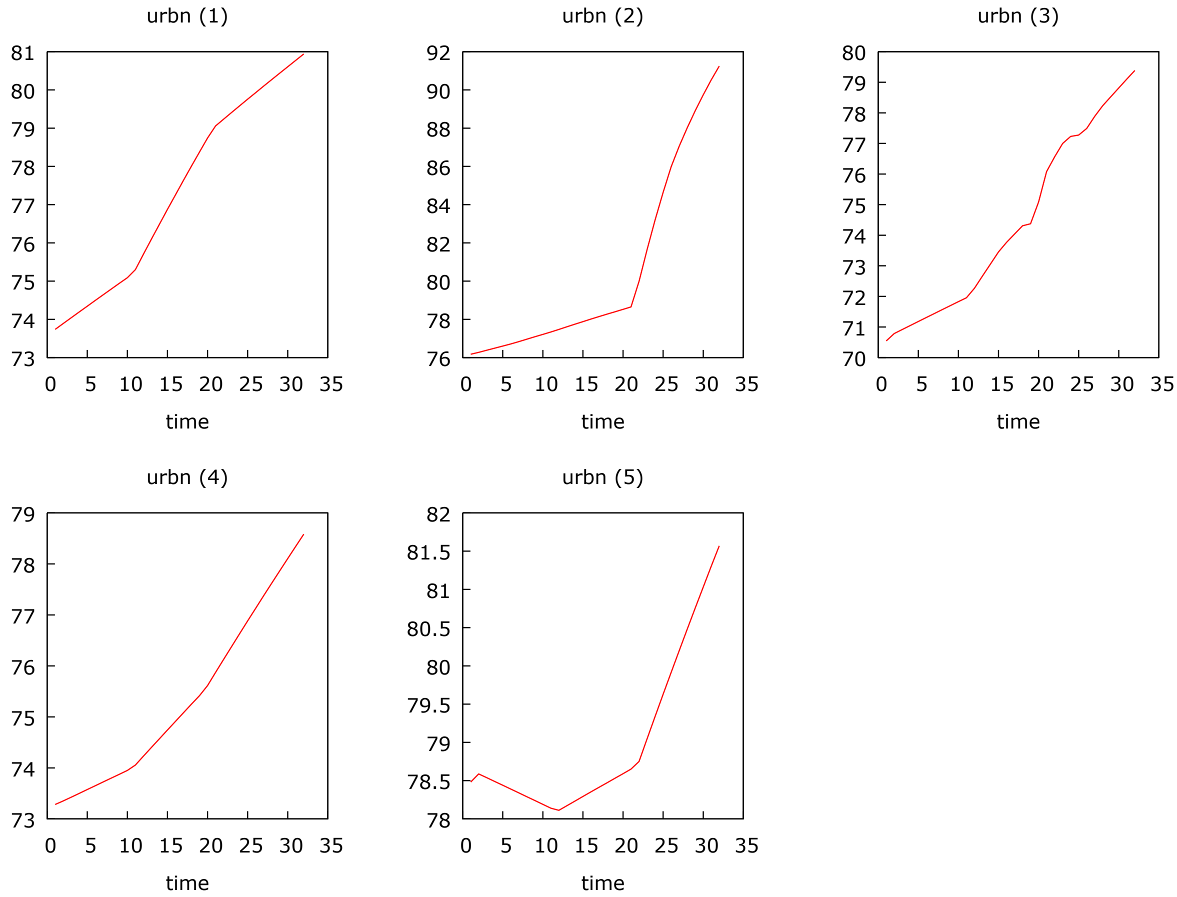
4- France

5- UK

Figure 15 shows that the aggregate levels of fossil fuel intensity observed in the countries under study. Particularly for the US (panel 1) l, Norway (panel 3) and UK (panel 5), it can be observed that the fossil fuel intensity has expanded at a faster pace compared to the other nations in this group. While US has shown a sustained rise in fossil fuel intensity throughout the period under study, the same in Norway and UK seems to have picked up since the year 1997. Presence of significant domestic hydrocarbon reserves in these countries can be pointed out as the major reason for the high share of carbon in their overall energy consumption. However it can be observed from figure 13 and 14 that, the carbon intensity and energy intensity of such countries has been declining persistently. Transition from polluting and inefficient fuels like coal and crude oil to the more efficient low carbon natural gas is the most likely justification for such an inconsistent observation. For example, in the US, the share of natural gas as a proportion of total electricity generation mix rose from about 15% in 1980 to about 30% in 2010 (doubling in a span of 30 years) (Energy Information Administration, USA). In case of France, one can observe the remarkable drop in the intensity of Her carbon intensity energy consumption. This can be attributed to the economy's reliance on nuclear energy (75% of total electricity production) for powering the same. In case of Japan, one cannot find a dominant feature in the fossil fuel intensity trends of Her economy.

The proportion of urban population as a variable impacting carbon intensity has been found to be significant at individual country levels for all nations except Japan.

Figure 16: Proportion of Urban Population (Dev)



Note:

1 – US

2- Japan

3- Norway

4- France

5- UK

Figure 16 shows the trends observed in proportion of urban population in such countries. Sustained urbanization can be observed in all the given countries. The fixed effects model, though indicating an insignificant relationship, demonstrates a positive relationship between carbon intensity and proportion of urban population in developed nations. Energy intensive urbanization in developed countries is a much documented phenomenon and hence the results are unsurprising.

In order to further reduce the carbon intensity of the developed countries, policies must aim at the reduction in the energy intensity. In countries with substantial hydrocarbon resources, usage of fossil fuels must be brought down and renewable energy technologies should be promoted. Also promoted should be low carbon lifestyles in such countries in order to mitigate the ill effects of urbanization.

5.2.Developing Countries

Model 5.2.1. : Heteroskedasticity-corrected, using 160 observations

Dependent variable: ci

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1.11413e-07	1.88196e-08	5.9200	<0.0001	***
ei	235.538	4.88765	48.1904	<0.0001	***
d_fi	5.99479e-010	1.63517e-09	0.3666	0.7144	
d_urbn	6.97144e-010	1.67365e-09	0.4165	0.6776	
dchn	7.48951e-08	6.73583e-08	1.1119	0.2679	
dbrz	−2.36024e-07	4.26874e-08	−5.5291	<0.0001	***
drsa	−4.80704e-07	6.82917e-08	−7.0390	<0.0001	***
dindo	−2.33699e-07	6.8006e-08	−3.4364	0.0008	***

Significance: *** (1%) ** (5%) * (10%)

Statistics based on the weighted data:

Sum squared resid	513.0109		S.E. of regression	1.837137
R-squared	0.940720		Adjusted R-squared	0.937990
F(7, 152)	344.5867		P-value(F)	7.60e-90
Log-likelihood	−320.2400		Akaike criterion	656.4801
Schwarz criterion	681.0815		Hannan-Quinn	666.4698

Statistics based on the original data:

Mean dependent var	5.68e-07		S.D. dependent var	1.63e-06
Sum squared resid	6.56e-12		S.E. of regression	2.08e-07

As per the pooled OLS estimates, only energy intensity has been found to have a statistically significant (at 1% level of significance) positive relationship with carbon intensity in developing countries. It is reported that on an average, unit increase in energy intensity in developing countries leads to a 235.5 kt/ unit of GDP rise in carbon intensity. Also observed is the significance of country specific dummies in case of Brazil, South Africa and Indonesia (at 1% level of significance). This implies that the respective country specific carbon intensity functions have varying intercepts. The model doesn't indicate the significance of relationship of fossil fuel intensity and proportion of urban population with carbon intensity, though the same have a positive relationship with the same.

Model 5.2.2. : Fixed-effects, using 160 observations

Included 5 cross-sectional units

Time-series length = 32

Dependent variable: ci

Robust (HAC) standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−1.64188e-07	1.67716e-07	−0.9790	0.3292	
ei	232.793	2.02362	115.0375	<0.0001	***
d_fi	2.96505e-09	3.02255e-09	0.9810	0.3282	
d_urbn	−5.1906e-010	1.13335e-09	−0.4580	0.6476	

Significance: *** (1%) ** (5%) * (10%)

Mean dependent var	5.68e-07		S.D. dependent var	1.63e-06

Sum squared resid	6.23e-12		S.E. of regression	2.02e-07
LSDV R-squared	0.985282		Within R-squared	0.982298
LSDV F(7, 152)	1453.650		P-value(F)	8.8e-136
Log-likelihood	2243.135		Akaike criterion	−4470.270
Schwarz criterion	−4445.669		Hannan-Quinn	−4460.280
rho	0.712586		Durbin-Watson	0.528337

Joint test on named regressors -

Test statistic: F (3, 152) = 2811.54

With p-value = P (F (3, 152) > 2811.54) = 6.93119e-133

The basic fixed effects model also indicates the significance of the positive relationship between carbon intensity and energy intensity (at 1% level of significance), with the other two being found to be insignificant. The magnitude of change in carbon intensity caused by energy intensity, compared to the pooled OLS model is slightly less at 232.7 kt/ unit of GDP.

Model 5.2.3. : Fixed-effects, using 160 observations

Included 5 cross-sectional units

Time-series length = 32

Dependent variable: ci

Robust (HAC) standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−1.0781e-07	1.06556e-07	−1.0118	0.3133	
ei	220.81	71.4104	3.0921	0.0024	***
d_fi	−5.13822e-010	8.65149e-010	−0.5939	0.5535	

d_urbn	7.73027e-010	5.12145e-010	1.5094	0.1334	
$dchn_i$* d_fi_{it}	−1.12542e-08	6.14556e-010	−18.3127	<0.0001	***
$dchn_i$*d_urb_{it}	−1.27017e-09	5.7592e-010	−2.2055	0.0290	**
$dbrz_i$*ei_{it}	15.6119	71.413	0.2186	0.8273	
$dbrz_i$* d_fi_{it}	1.11674e-08	1.05108e-09	10.6247	<0.0001	***
$drsa_i$* d_fi_{it}	1.95308e-08	1.1074e-08	1.7637	0.0799	*
$drsa_i$*d_urb_{it}	2.33216e-09	2.69805e-09	0.8644	0.3888	
$dindo_i$* d_fi_{it}	−7.63017e-08	5.11644e-08	−1.4913	0.1381	
$dindo_i$*d_urb_{it}	8.056e-08	5.24492e-08	1.5360	0.1267	

Significance: *** (1%) ** (5%) * (10%)

Mean dependent var	5.68e-07		S.D. dependent var	1.63e-06
Sum squared resid	4.25e-12		S.E. of regression	1.72e-07
LSDV R-squared	0.989947		Within R-squared	0.987909
LSDV F(15, 144)	945.3186		P-value(F)	1.2e-135
Log-likelihood	2273.629		Akaike criterion	−4515.258
Schwarz criterion	−4466.055		Hannan-Quinn	−4495.278
rho	0.591753		Durbin-Watson	0.783162

Joint test on named regressors -

Test statistic: F (11, 144) = 1069.56

With p-value = P (F (11, 144) > 1069.56) = 4.23869e-132

F-test (8, 152) = 0.005 (not significant)

In case of the fixed effects model with interaction dummies, once again only energy intensity has been found to be the lone significant explanatory variable, with the impact on carbon intensity found to be reduced at 221 kt/ unit of GDP. Also found, is the statistical significance of difference in the impact of the respective fuel intensities w.r.t that of the base country (India), in the case of China (by -0.0000000112 kt/ unit of GDP) and Brazil (by -0.0000000111 kt/ unit of GDP). Difference w.r.t the base country can also be observed in case of the variable proportion of urban population for China (by -0.00000000127 kt/ unit of GDP).

The insignificance of the F-statistic reveals that there is not much difference between the basic fixed effects model and the model with interaction dummies.

Model 5.2.4. : Random-effects (GLS), using 160 observations

Included 5 cross-sectional units

Time-series length = 32

Dependent variable: ci

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−1.35587e-07	1.51123e-07	−0.8972	0.3710	
ei	232.556	2.53512	91.7337	<0.0001	***
d_fi	2.61699e-09	1.95306e-09	1.3399	0.1822	
d_urbn	−5.38772e-010	1.93672e-09	−0.2782	0.7812	

Mean dependent var	5.68e-07		S.D. dependent var	1.63e-06
Sum squared resid	1.60e-11		S.E. of regression	3.19e-07
Log-likelihood	2167.753		Akaike criterion	−4327.506
Schwarz criterion	−4315.206		Hannan-Quinn	−4322.511

Significance: *** (1%) ** (5%) * (10%)

'Within' variance = 4.09767e-014

'Between' variance = 9.18162e-014

Theta used for quasi-demeaning = 0.881904

Breusch-Pagan test -

Null hypothesis: Variance of the unit-specific error = 0

Asymptotic test statistic: Chi-square (1) = 239.285

With p-value = 5.63073e-054

Hausman test -

Null hypothesis: GLS estimates are consistent

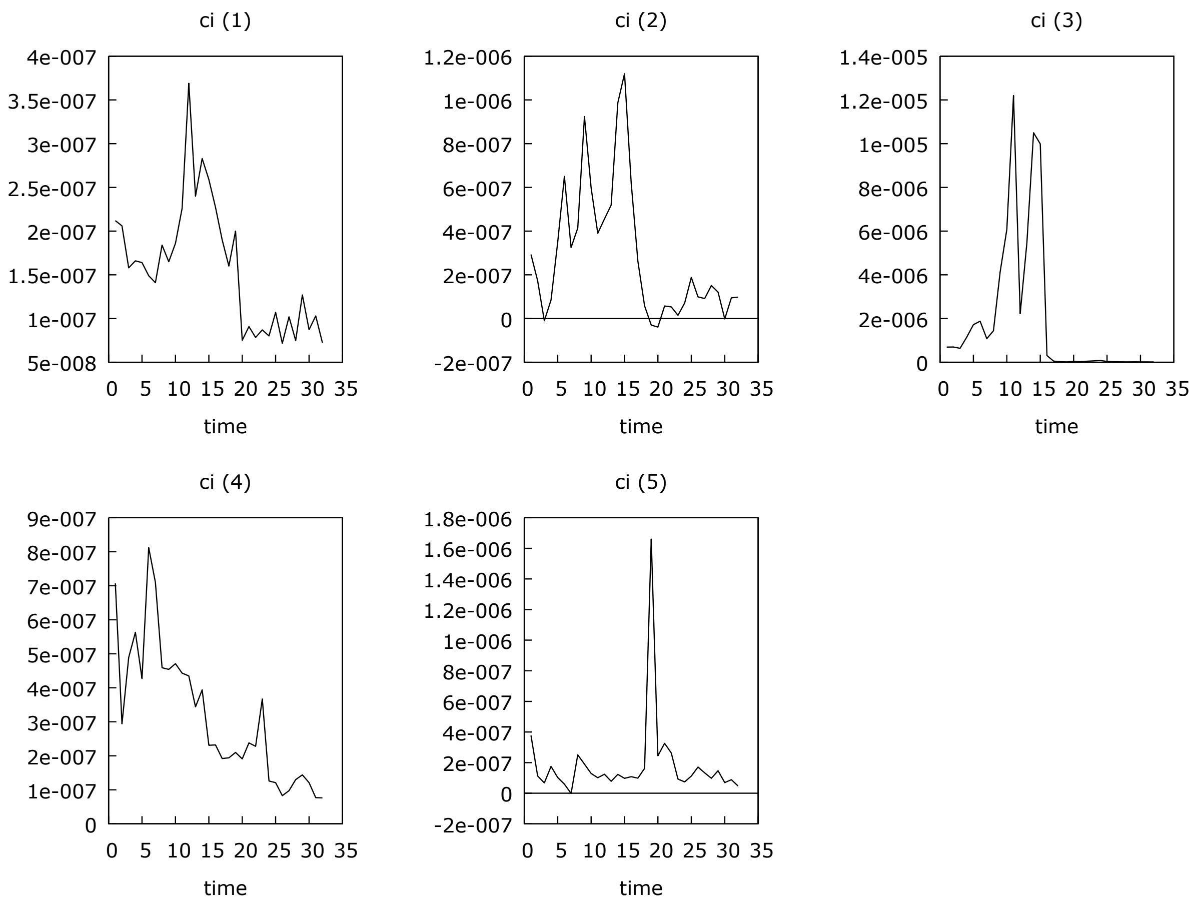
Asymptotic test statistic: Chi-square (3) = 2.59724

With p-value = 0.457973

The random effects model suggests that energy intensity alone is significant in explaining the variation in carbon intensity in developing nations. It has been observed that for every one unit change in energy intensity, the carbon intensity rises by 232.5 kt/ unit of GDP. The insignificance of Chi square statistic validates the usage of this model for further analysis.

The analysis conducted above indicates that energy intensity is the lone variable that has a significant impact on the carbon intensity of developing countries.

Figure 17: Carbon Intensity (Devl)



Note:

1 – India

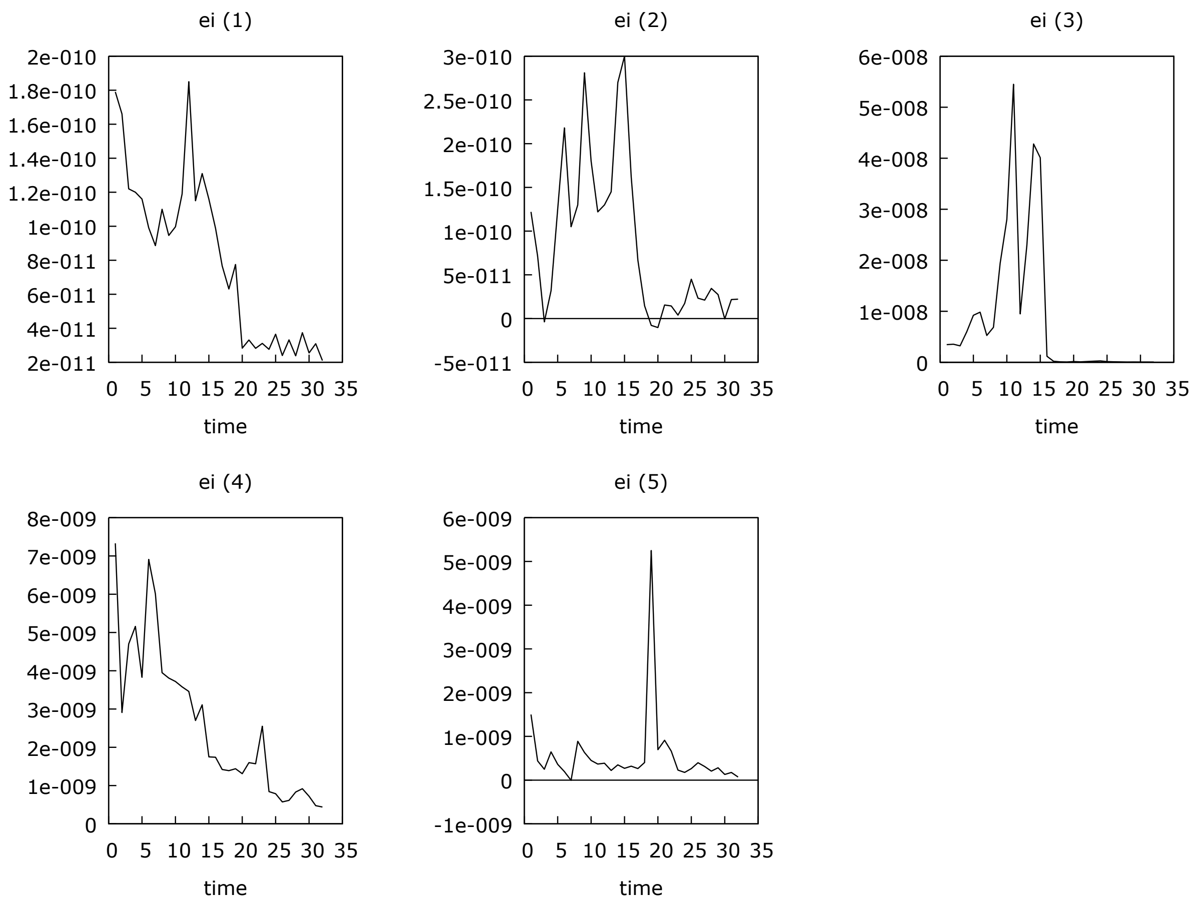
2- China

3- Brazil

4- South Africa

5- Indonesia

Figure 18: Energy Intensity (Devl)



Note:

1 – India

2- China

3- Brazil

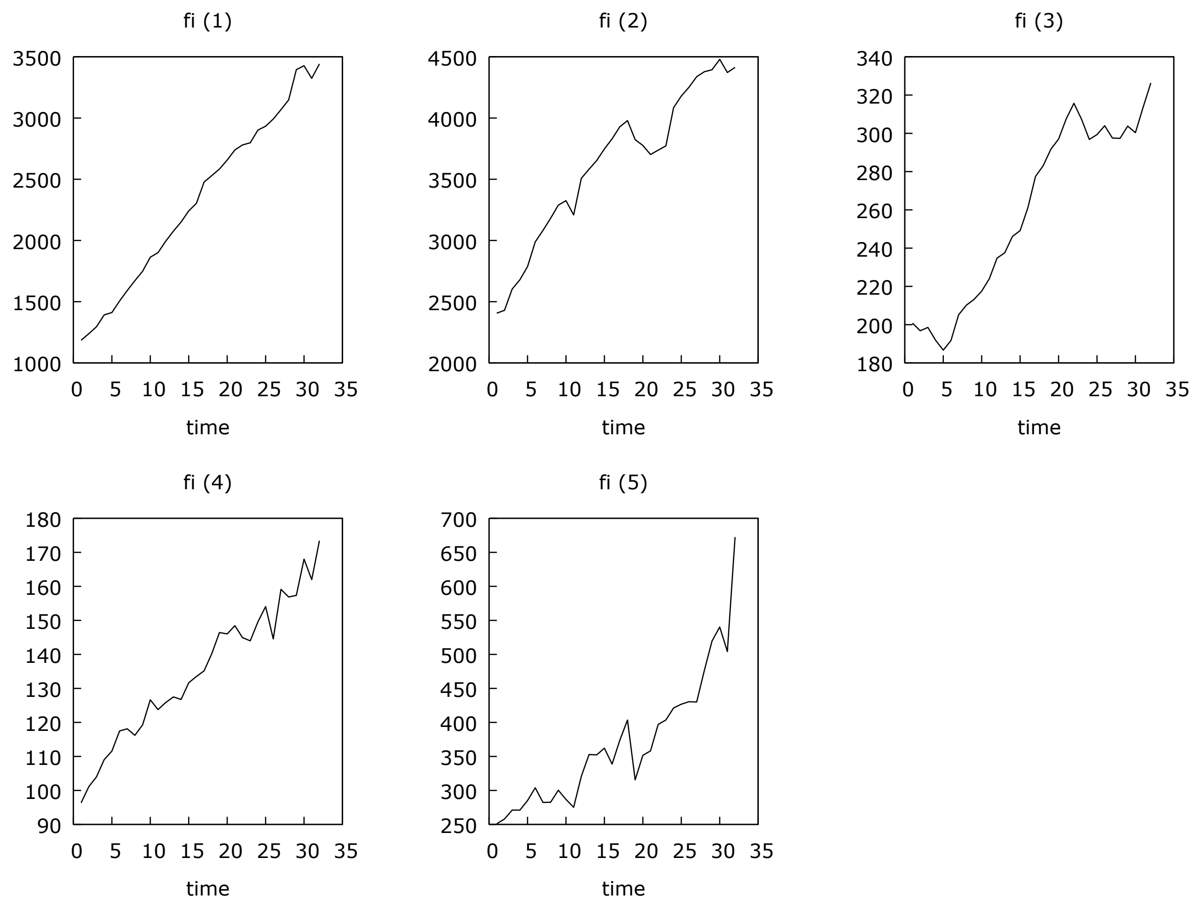
4- South Africa

5- Indonesia

It was found that there is a strong correlation between carbon intensity and energy intensity in developing countries, with a correlation coefficient of 0.98. The same can be observed in the figures 17 and 18, displayed above. Over the course of the period under study, energy intensity and consequently carbon intensity have shown a declining trend. Given the fact that the group consists largely of countries undergoing industrialization at a rapid pace it can be observed from the respective figures that for most of the period under study, the absolute value of the variables under consideration is relatively high compared to the levels observed in the case developed countries analyzed above. However with the adoption of more efficient technologies and transition to cleaner fuels like natural gas and ethanol (in case of Brazil), the energy intensity and carbon intensity have progressively declined. It is therefore no surprise that energy intensity has been found as the sole variable impacting carbon intensity in developing nations.

However, the contribution of fossil fuel intensity in the determination of carbon intensity cannot be ignored.

Figure 19: Fossil fuel intensity (Devl)



Note:

1 – India

2- China

3- Brazil
4- South Africa
5- Indonesia

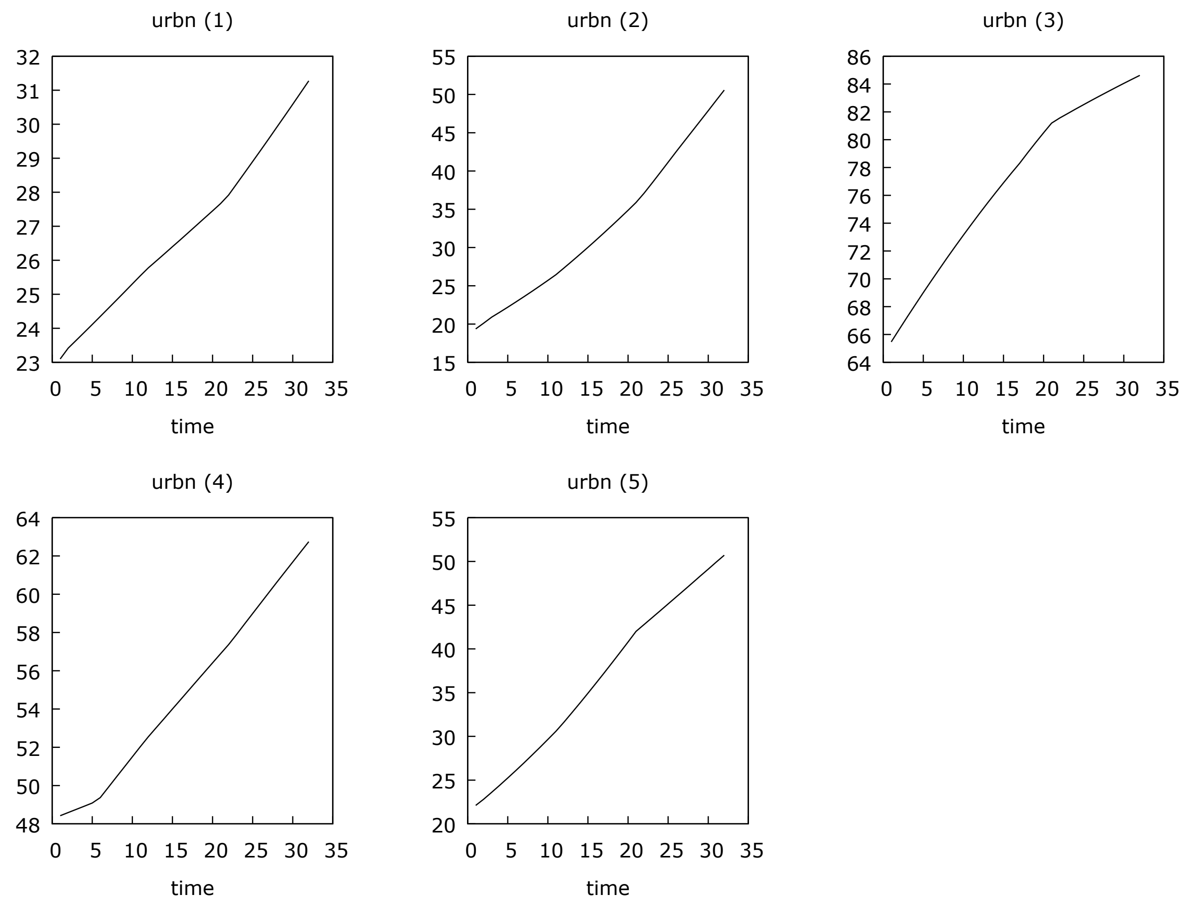
Fossil fuel intensity shows a rising trend in the developing countries, despite the contraction of carbon and energy intensities. In other words, even though energy intensity is falling in developing countries, carbon intensity of the energy consumption is increasing. Unlike the developed nations, natural gas consumption has not taken off in developing countries. Therefore it appears that implementation of energy efficient technology and usage of equipment have contributed to the fall of energy intensity and consequently carbon intensity in such countries.

Proportion of urban population as an independent variable (though insignificant) has been found to have a negative relationship with carbon intensity. Given that these countries are among the fastest growing major economies of the world, the results imply that an increase in urbanization in these two countries has led to the decrease in the carbon intensity of the same. The likely reason for this relationship can be attributed to the sustained rural urban migration taking place in these countries. Carbon emitting biofuels are the major energy source for the rural populace in such countries. Rapid urbanization in such countries has led to the adoption of cleaner fuels like ‘Liquefied Petroleum Gas’ and electricity, leading to an overall reduction in the carbon footprint.

Therefore policy measured seeking to reduce carbon intensity in developing countries should aim at reducing the energy intensity of such economies. Such reduction can be achieved by deeper adoption of fuel efficient technologies along with augmentation of renewable energy capacity in these countries. Besides, the developing economies should pursue policies geared to promote greater usage of clean fuels in the rural regions along with better management of urban areas.

Therefore policy measures seeking to reduce carbon intensity in developing countries should aim at reducing the energy intensity of such economies. Such reduction can be achieved by deeper adoption of fuel efficient technologies along with augmentation of renewable energy capacity in these countries. Besides, these major growing developing economies should pursue policies geared towards better urban planning and management for mitigating the rise in energy intensity and thereby carbon intensity accompanying accelerated urbanization.

Figure 20: Proportion of Urban Population (Devl)



Note:

1 – India

2- China

3- Brazil

4- South Africa

5- Indonesia

6. Policy Recommendations and Conclusions

6.1.Policy Recommendations

6.1.1. Developed Countries:

1. Take further measures (both technical and economic) to promote usage of energy efficient technologies to further curtail the energy intensity of the respective economies.
2. Reduce the consumption of fossil fuels in order to reduce fossil fuel intensity especially in the context of countries with good fossil fuel reserves.
3. Promote the employment of renewable energy like solar, wind and bio fuels in order to aid reduction in fossil fuel intensity.
4. Promote low carbon lifestyles, especially in urban areas so as to reduce the carbon footprint in such countries.

6.1.2. Developing Countries:

1. Reduce energy intensity through enhanced adoption of energy efficient technologies and equipment
2. Reduce the consumption of fossil fuels like coal and oil in order to bring down the fossil fuel intensity of energy consumption.
3. Promote the cleaner and more efficient natural gas as a replacement for Coal and crude oil, for enabling simultaneous reduction in energy and fossil fuels intensities
4. Promote adoption of renewable energy to aid further the reduction of fossil fuel intensity
5. Provision for the usage cleaner energy sources like ‘ LPG’ and electricity in rural centres
6. Plan and implement better urban management programmes for reducing the carbon footprint of the newly urbanized centres.

6.2.Conclusion

This dissertation aimed at determining the factors impacting carbon intensity in developed and developing countries. A comprehensive review of the literature enabled the construction of the hypothesis that carbon intensity is a function of energy intensity, fossil fuel intensity and proportion of urban population. Accordingly data for 5 countries under each category of developed and developing countries was collected. After checking for stationarity, panel regression analysis was conducted. For developed countries it was found that the fixed effects model with interaction dummies was the most suitable for analyzing the results for such category. On the other hand for developing countries, the random effects model was found to be suitable.

In case of the developed countries, energy intensity was found to be the most significant variable impacting the carbon intensity at the aggregate level. Differences between countries w.r.t to the variables fossil fuel intensity and proportion of urban population was observed. Such variables, though impacting carbon intensity in a positive manner, were found to be insignificant. Analyzing the results, it was concluded in case of developed nations, enhanced utilization of energy for economic activity was compensated by the utilization of energy efficient technologies and cleaner fossil fuels like natural gas. Taken together, this has had a net impact of reducing the carbon intensity of such economies. Such countries should continue to promote energy efficiency improvements in their economic activities along while enhancing substitution of fossil fuel based energy sources with clean and green sources like natural gas, renewables and biofuels. Also promoted should be low carbon lifestyles, especially in urban areas so as to reduce the carbon footprint in such countries.

In the case of developing countries on the other hand, taken as a whole energy intensity is the only variable that has a statistically significant influence on carbon intensity. Though insignificant, fossil fuel intensity shows a rising trend in such economies. But collating the same with the fact of falling energy and carbon intensities, it can be made out that enhanced fossil fuel usage is being compensated by augmented usage of energy efficient technologies in these nations. Also, despite the insignificance of the variable proportion of urban population, it can be argued better urban planning is key to reduce the energy intensity and thus carbon intensity of such economies. Recommendations for such countries include enhanced adoption of energy efficient technologies and equipment, reduction in the consumption of fossil fuels and promotion of renewables. Also required is the provisioning for the usage of relatively clean fuels like ‘LPG’ and electricity in rural areas along with implementation of better urban management programmes in such countries.

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