# IMPACT OF AFFLUENCE, POPULATION GROWTH AND TECHNOLOGY ON ENVIRONMENT IN TERMS OF $CO_2$ EMISSION IN DEVELOPING, DEVELOPED AND LEAST DEVELOPED ECONOMIES

**By**

**Sharma Ashwani Kumar**

**THESIS**

*Submitted to*
*KDI School of Public Policy and Management*
*in partial fulfillment of the requirements*
*for the degree of*

MASTER OF PUBLIC POLICY IN ECONOMIC DEVELOPMENT

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Approval as of August, 2013.

# ABSTRACT

**IMPACT OF AFFLUENCE, POPULATION GROWTH AND TECHNOLOGY ON ENVIRONMENT IN TERMS OF $CO_2$ EMISSION IN DEVELOPING, DEVELOPED AND LEAST DEVELOPED ECONOMIES**

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Global warming is a tangible reality. Green House Gases (GHGs) are the main cause of this world-wide phenomenon. Since the middle of last century there has been an abrupt increase in GHG emission because of high anthropogenic pressure and fast economic growth in many parts of the world. Because of environmental concern all over the world there have been concerted efforts to cope up with this problem. Myriads of empirical studies were carried out and policy decisions were taken to contain $CO_2$ emission. This study is also undertaken to examine that which of the factors out of population growth, economic development and technological advancements cause more damage in terms of $CO_2$ emission. Then behavior of the most harmful factor is analyzed in Environmental- Kuznets – Curve to search a solution to this problem. This is accomplished through widely used models viz. IPAT model and Environmental –Kuznets –Curve (EKC). The impact on environment in terms of $CO_2$ emission is measured in 21 economies of the world comprising of seven in each three categories viz. developing, developed and least developed economies. The decompositionidentity of IPAT model is used in this study to identify the most harmful factor. It is found that the economic growth i.e.GDP per capita iscausing more damage to the environment in terms of $CO_2$emission than population growth in

developing and developed economies.

However, in least developed economies technological factor is causing severe damage. It is because of the reason that poor countries are not in a position to adopt environmental friendly technologies particularly for energy production. The relationship of $CO_2$ emission and economic growth is then subjected to analysis in EKC. However, no ideal relation of inverted U shaped curve is found in any of the countries. However, in case of UK, France and Germany negative relation between $CO_2$ emission and GDP per capita is observed. In case of fast growing economies viz. India, China, Indonesia, Malaysia and Bangladesh direct positive relation is found. In case of USA, Canada and Japan, a different 'N' shaped curve is observed. In this study it is found that $CO_2$ emission depends upon complex interactions of all three variables i.e. population pressure, economic growth and technology. The countries like Germany, France and UK where the policies of environmental protection are widely adopted and clean technologies are used in energy production $CO_2$ emission has been contained. The least developed economies like Liberia, Rwanda and Madagascar are causing severe damage to the environment. In present scenario of globalization the most harmful factor for release of $CO_2$ is economic growth in developed and developing economies. However, in case of least developed economies technological factor is responsible for greater damage. It is also found that $CO_2$emission does not follow inverted 'U' shaped curve as has been envisaged in Environmental – Kuznets –Curve.

**Dedicated**

**To**

**The cause of Mother Earth**

## ACKNOWLEDGEMENTS

The completion of this document is indeeda great moment of my life. My dream of getting a Master Degree from a coveted institute has now been realized.

I could have not completed this thesis had I not received an impeccable and flawless guidance, advice and motivation from Prof. Dong-Young Kim, my Major Professor and Prof. Jung Kwon, Co-Professor, of KDI School of Public Policy. Apart from academic support, the compassion they showered is inexplicable. It is not out of place to mention here that their doors always remained opened for me whenever I was in need of help.

Getting education in this world famous institute could have not been possible for me had I not received financial assistance in form of POSCO Asia Fellowship. I'll remain indebted to POSCO TJ Park Foundation for awarding me prestigious fellowship for pursuing studies in KDI School of Public Policy and Management, Seoul.

It would be unfair if I don't acknowledge the help received from the Management, the Professors and the staff members of the School throughout my stay. The state-of-the-art facilities provided by the School are highly appreciated.

I am also grateful to the Government of Himachal Pradesh and Department of Personnel to the Government of India for allowing me to undertake this degree course.

I feel short of words to express my feelings of indebtedness to my son - Rijul and wife–Geeta, who had came across a tough time in my absence.Their incessant moral support encouraged me to successfully accomplish this venture.

Last but not least, I solely claim the responsibility of omissions and commissions in this work.

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# ABBREVIATIONS

| | | |
|---|---|---|
| A | : | Affluence |
| $CO_2$ | : | Carbon Dioxide |
| EKC | : | Environmental- Kuznets- Curve |
| GDP | : | Gross Domestic Product |
| GHGs | : | Green House Gases |
| I | : | Impact |
| Kgt | : | Kilo Giga Tones |
| LDCs | : | Least Developed Countries |
| P | : | Population |
| T | : | Technology |

# INTRODUCTION

*"Warming of the climate system is unequivocal as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."*[1]

(IPCC, 2007)

The global warming is now a tangible reality and has candidlybeen admitted by Intergovernmental Panel on Climate Change (IPCC) in its 4th Assessment Report. It is not merely an academic concept butphysical and biological systems too have started experiencing the effects of this global phenomenon (IPCC, AR4, 2007). Melting of ice at Arctic regions; receding of mountainousglaciers around the world; shifting of agro climatic zones in some of the parts of world; extinction of species; vagaries and extremities of weather; prevalence of Tsunamis etc. all speak volumes of global warming.

The causes of Global warmingare too known– hugeaccumulation of Green House Gases (GHGs)[2] in earth's atmosphere. Although,the anthropogenic activity has been an integral part of earth's environment since the onset of civilization, yet,its impact was not detrimental when population pressure was minimal; mother earth was rich in natural resources; man was judicious in their use; and more importantly the greed for money was least. The civilization evolved, survived and progressed in the lap of 'Mother Earth' by judiciously utilizing its natural resources. However, after

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[1]This report of IPCC, adopted section by section at IPCC ( Intergovernmental Panel on Climate Change) Plenary XXVII ( Valencia, Spain, 12-17 Nov, 2007), represents the formally agreed statement of the IPCC concerning Key findings and uncertainties, contained in the working group activities to the Fourth Assessment Report.
(http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf)

[2] Green House Gases (GHGs) are water vapors, carbon dioxide ($CO_2$), methane (CH4), nitrous oxide ($N_2O$), and halocarbons (CFCs). However, after water vapors the major GHG gas is $CO_2$.

industrialization in 16th, 17th and 18th century, in somepockets of the world demand for natural resources increased. This resulted into colonization by industrialized nations. In 20th century after World War II most of these colonies got independence. As a result, there was an upsurge in developmental and economic activities in third world countries. Consequently there was increase in prosperity, population and advancements in technology resulting into pressure on environment for natural resources. The result ismyriad of environmental problems. This also contributes to the accumulation of GHGs resulting into Global Warming. The magnanimity of the problem can be gauged from the fact that the countries around the globe are crying hoarse to contain the GHGs emission to save the earth. As an estimate, if GHGs emissionis not contained the global average temperature is expected to rise 1 to 3.5$^{o}$C by 2100 AD (O' Neill et al. 2001). If it happens so it would mean nothing but a catastrophe.

This situation has kindled/sparkeda serious concern on environmental degradation and global warming. There have been a constant and all round efforts to understand the drivers of this global phenomenon. Indiscreet use of natural resources for economic activity and release of GHGs and pollutants as a byproduct has resulted into eruption of intense debate on the role of high economic growth, population explosion and technological advancements in global warming.In addition, there has also been a paradigm shift in national and international policies to check global warming by limiting GHGs emissions around the globe. That is why the world community through international organizations like UN, IPCC and the like, urging all the nations to reduce $CO_2$ emission through various international protocols like that of Kyoto, 1992.

Obviously, with an increase in the concern for environmentthere has been an upsurge in academic activities to understand various factors, actors and aspects of global warming. It is in this context that this study is being undertaken to examine the interrelationship between the drivers responsible for $CO_2$ release to explore the policy solutions.

## 1. Problem definition

After World War II some phenomenonbecame conspicuous all around the world. These are - an abrupt increase in population in third world countries; rapid economic growth by erstwhile colonies; technological advancements; and emergence of serious environmental problems. Amongst environmental problems global warming; scarcity of water; reduction in agriculture productivity; depletion of forest wealth; air water and soil pollution became all pervasive. Out of them global warming became such a serious problem that it is affecting the world community badly and without discrimination. It originates locally and spreads globally. It also requires great deal of efforts, time and resources to manage.

The global warming is caused by a number of factors like trapping heat by GHG gasses, volcanic eruption, Sun's output, earth's movement etc. However, the major man made factor isrelease of GHGs into the atmosphere.Following table gives a snapshot of various GHGs and their potential to harm environment.

**Table1.Extent of harm Green House Gases (GHGs)can cause.**

| **Gas** | **Concentration (ppb)**[a] | | **Current Growth (% per year)** | **Life time** [b] **(years)** | **Radioactive forcing ( per molecule relative to $CO_2$)** | **100 year global warming potential (relative to $CO_2$)** |
|---|---|---|---|---|---|---|
| | **Pre Industrialized** | **1994** | | | | |
| **$CO_2$** | **280,000** | **358,000** | **0.5** | **100**<br>**(>10 4**<br>**(25-50%**<br>**)50-75%)** [C] | **1** | **1** |
| **$CH_4$** | **700** | **1720** | **0.5** | **12.2** | **21** | **21** |
| **$N_2O$** | **275** | **312** | **0.3** | **120** | **206** | **310** |
| **CFC-12** [d] | **0** | **0.503** | **1.4** | **102** | **15,600** | **6200 – 7100** |

[a]*ppb : parts per billion*

[b]*Life time is defined as the average length of time a present emission will continue to affect atmospheric concentrations.*

[C]*From O'Neill et al. (1997). The atmosphere'sresponse to a $CO_2$ emission has a distinctly dual nature : at least half the effect of emission is removed in about 100 years, while the remainder persists for tens of thousands of years or more. The exact fractions and time scales of persistence depend on the assumed future concentration scenario.*

[d]*CFC-12 is use here as a representativeexample of the chlorofluorocarbons (CFCs), an important subclass of the halocarbons.*

**Source : Schimelet al (1996) ; O' Neill et al (1997)**

Above factsclearly indicate that GHGs are harmful in the long run. In the above table $CO_2$seems to cause major damage being released in bulk. It is mostly released by the burning of fossil fuels for energy production and production of consumer goods. The impacts are potentially high as energy production from fossil fuels is a primary component of the most of the economies. Also as the consumer market is expanding with the production of consumer goods the situation is becoming more critical in the era of fast economic development. The depletion of forest wealth further reduces $CO_2$ sequestering giving rise to accumulation of $CO_2$ in the atmosphere.

In addition, some issues further complicate the problem. Firstly, there is considerable uncertainty on making projections as to how much global warming would occur in future, how severe the problem would be and how costlier the efforts will be. Second is that the effects of today's GHG emission are felt in future which makes it impossible to wait and see how severe impacts will be before taking preventive measures. Thirdly, the GHG emissions are spread over the nations, no single nation can reduce the global warming by cutting its individual emissions. Hence, the solution to the problem is global (O' Neill et al. 1997).

This study is going to touch upon the drivers of $CO_2$ emission. Firstly, three drivers of $CO_2$ emission viz. population growth, economic development and technological advancements would be subjected to analysis in IPAT model to find out which of the three variables is more harmful in terms of contribution to the release of $CO_2$. Then, the relation between the most harmful driver and $CO_2$ emission will be studied along the developmental paths of three categories of nations viz. developed, developing and least developed countries through Environmental-Kuznets-Curve (EKC).

Accordingly, the problem and hypothesis formulation is explained and defined in following major heads viz. population pressure versus $CO_2$ emission; economic growth versus $CO_2$ emission; and technology and $CO_2$ emission.

**(a) Population versus $CO_2$ emission**

Neo-Malthusian theorydescribesincompatibility between demographic growth and preservation of environment. More precisely, it states that population growth in developing and least developed economies have negative impact on environment. Meaning-thereby, the increase in demand for natural resources and their derived products puts constraint on limited common pool resources like air, water, space, earth etc. This kind of anthropogenic pressure is directly connected to $CO_2$emission (Dyson, 2005). In nutshell, the Neo-Malthusian Environmentalists held responsible the abrupt population growth for environmentaldegradation. They consider thatconcept of 'carrying capacity' holds true for environment and economy because of increased population more precisely in developing nations (O' Neill et al. 2001). Meadows et al. (1972) attempted to test this hypothesis of incompatibility between population growth and environment. They found that results would be catastrophic because of exhaustion of some of the non-renewable resources. However, that did not happen.

Subsequently, Neoclassical population – development – environment model came which explains that population does necessarily not exert negative impact on environment. This is true under neoclassical assumptions in free tradescenario and perfectly competitive markets; and efficient allocation of property rights. According to Panayotou (1994) international trade has capability to offset the detrimental impact of population growth because of trading of scarce resources (ecological capital); substituting and importing new technologies (substitution argument); undertaking less resource intensive production(Ricardo's comparative advantage).

Hence, this is hypothesized that in comparison to population pressure, the economic growth has more detrimental effect on environmental impact in terms of $CO_2$ emission.

**(b) Economic growth versus$CO_2$ emission**

It is observed that release of $CO_2$ is abruptly high is fast developing countries like China, India and South Africa. As a thumb rule the fast growing economies are being blamed for higher emission of $CO_2$. For last two decades there has been a heated debate between developed and developing economies on the issues of release of $CO_2$. The developedeconomies claim that western model of capitalism is more environmental friendly than developing economies because of the fact that the developing economies use fossil fuel for most of the energy production. Also the technologiesin the poor countries and developing countries are not developedto the extent which can take care of polluting substances. As per rough estimates BRICS(Brazil, Russia, India, China and South Africa)economies contribute to about 25 % of total global GHG emission and is expected to rise up to50 % by 2050 if they keep on emitting at same pace.It is a fact that poor and least developed economies areby-and-large, using fossil fuel as the main source of energy which is a major deviation from developed economies of the west in terms of production and consumption pattern.

The major fear in the developing and least developed economies is that if any kind of restriction is imposed to contain the release of $CO_2$, it will adversely affect their economic growth. Consequently,the most of the poor of the world will remain embroiled in themorasses ofabjectpoverty.However, the developed economies area emphasizingon clean and green growth by the use of environmental friendly technologies and clean sources of energy.

The moot question here is whether there is trade- off between high economic growth and high standards of environmental quality. According to Molinas (2010), "the basic conclusion is that economic growth under perfect market conditions is not harmful for the preservation of natural resources."This is based upon the principle of neoclassical model which states that with the rise in income the demand for environmental quality rises (Panayotou, 1994).

There is another school of thought whichfirmly argues that the fastest road to environment improvement is to achieveeconomicdevelopment as quickly as possible. They believe that as the income grows, the demand for environmental friendly goods, services, technologies and clean energies increases. Beckerman (1992) says, “The strongest correlation between income and expenditure to which environmental protection measures are adopted demonstrates that in the long run, the surest way to improve environment is to become rich.”Barlett (1998) explained that environmental regulations whichcontain economic growth reduce the environmental quality. There are others who claim that relationship between economic growth and environmental quality, whether positive or negative, is not fixed on a country’s developmental path. It may change as per the demand of the people for efficient infrastructure and cleaner environment (Selden and Sang, 1998).This theory was explained by Kuznets in his ‘EnvironmentalKuznets Curve’. He demonstrated the inverted ‘U’ relationship between environmental degradation and economic growth existsand is called as ‘EnvironmentalKuznets Curve’ and is analogous to income inequality relationship of Kuznets (1965). It states that after achieving a particular level of affluence, the demand for environmental goods, services and technologiesincreases.

Since 1990s this theory is attracting a great deal of attention. In its empirical studies it is explained that the importantindicators of environmental quality such as air pollution are improved as income level increases (Bruce et al. 2002). It also explains the role of technology in mitigation and amelioration of pollutant. Prior to this concept it was believed thatrichness and demographic pressure damage and destroy the natural resourceendowments at the faster rates.

All these concepts of environmental degradation i.e. (i) environmental degradation increases with economic development; it decreases with the economic development; or (iii) increases in the initial stages and decreases at later stages of economic development path of a country has immense policy implications. An increase in environmental degradation with economic growth would enforce such environmental regulations which could limit economic growth to barely a sustainable level of economic activity (Arrow et al. 1995). Decrease in environmental degradation with the increase in economic activity would force high economic activity to rapid environment improvement without any environmental regulations. If Environmental Kuznets Curve hypothesis fits in the evidence it is for sure that the economic development would certainly cause damage to the environment in short-run and would improve environment in long run. Hence, the environmental policies would not have much impact in the initial stages of the developmental path. However, after attaining a threshold the economy would automatically take care of the environment.

If Environmental – Kuznets- Curve is true for $CO_2$ emission then arise following issues: (i) what is that the level of that economic threshold from where turning point starts; (ii) how much environmental damage has to be borne for economic development in the initial stages of development; (iii) how is it possible to avoid necessary damage; (iv) will environmental improvements in long run be taken care by the economy automatically or does it need policy interventions. To address these issues great deal of empirical studies are required in all possible situations on the development paths of developed, developing and least developed economies. Hence, to find the answers to above questions relationship between economic development and $CO_2$ emission is being examined along the development path of three categories of the economy viz. developed, developing and least developed.

(c) **Technological advancements and Environment**

In the recent times it has been proved empirically that with the advancements in environmental friendly technologies of production and clean energy sources there has been reductionin the GHG emissionin some of the economies (Panayotou, 2003). This is attributed to the shifts in production technologies for green growthbroughtabout by the structural changes accompanying economic development(Grossman and Kreuger, 1991). Some others, as has been discussed above, have focused on the properties of preferences and the income elasticity of environmental quality(Mc Connel, 1997). However, still others have attempted some growth models with assumptions about the properties of both technology and preferences from which they derive Environmental Kuznets Curve (EKC) (Lopez, 1994). The model of Lopez (1994) consists of two important things – close relation between pollution and factors of production (labor and capital); and constant returns to scale and technical change and prices that are exogenously determined (Panayotou, 2003).It further states that with no or little tax on pollution prices, the growth results in higher pollution levels. However, when producers pay the full marginal social cost of the pollution they generate, the pollution-income relationship depending upon the properties of technology and of preferences.

> 'With homothetic preferences pollution levels still increase monotonically with income; with non-homothetic preferences, the faster the marginal utility declines with consumption levels and the higher the elasticity of substitution between pollution and other inputs, the less pollution will increase with output growth.'(Panayotou, 2003).

In case of water and air pollution this phenomenon was explained by 'inverted U shaped'relationship between pollution and income called as EKC. This phenomenon was shown in case of sulfur dioxide, nitrogen oxide, lead, DDT, sewage and other chemical released into the air and water. It also explains that where the environmental damagedirectly affects the consumers and pollution prices are near their marginal social costs, people become over cautious and turning points are achieved at relatively low income levels. In contrast, the turning points are found at much higher income levels or not at all for the pollutants where damage is less evident to the consumers. Selden and Song (1994) stated that there are two factors which contribute to an early and rapid increase in abatement. The first is on technology side, large direct effects of growth on pollution and a high marginal effectiveness of abatement. Second is on demand side (i.e. preferences), rapidly, declining marginalutility of consumption and rapidly rising marginal concern over mounting pollution levels.

## 2. Research Objectives

It is on the above backdrop that this study is undertakento assess the impact economic activity, populationincrease and technological advancements onenvironment in terms of $CO_2$ emission in developed, developing and least developed economies[3] of the World.

The study aims at finding answers to following questions:

**(a)** What is the impact of economic growth, technological advancements and population increase on environment in terms of $CO_2$ emission in developed, developing and least developed economies of the world?

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[3]The definition of Least Developed, Developing and Developed economies is used as given by United Nations Organization.

**(b)** Amongst three drivers of $CO_2$ emission viz. population pressure, economic growth and technology, which is the most harmful factor for $CO_2$ release?

**(c)** What is the relation between the most harmful factor and actual $CO_2$emitted on the development path of developed, developing and least developed nations?

Attempt is made to find answers to first two questions through IPAT[4] model developed by Ehrlich and Holdren(1971) and its variant (decomposition identity) developed by Bongaarts(1992) called as Decomposition method (discussed in details in following chapters). It is a simple model which serves twin objectives of assessing the environmental impact and testing the Neo-Malthusian theory.The relation mentioned in third question will be examined through Environmental Kuznets Curve (EKC)[5].

## 3. Research Contribution

This study is relying on two environmental models viz. IPAT model and Environmental- Kuznets- Curve. The variables which will be subjected to analysis are population growth, GDP per capita (economic growth) and $CO_2$ emission intensity. Hence, the basic idea is to study the pattern of $CO_2$ emission in different economies and along various stages of development so as to find out cogent relationwhich could help in containing $CO_2$ emission and ultimately global warming.

It will help in understandinghow economic growth, demographic pressure and technological advancements are affecting $CO_2$ emission in developing developed and least developed economies of the world.It may also help in throwing light as to

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[4]In IPAT model impact on environment( I) is equal to the product of population growth(P), affluence / economic growth(A) and technology(T).

[5] S Kuznets (1965) described inverted-U relationship between environmental degradation and economic growth (GDP per capita) known as Environmental Kuznets Curve (EKC).

whether the world will attain sustainable growth in perpetuity and without further increasing global warming.It willtell as to whether economic development takes care of environment at its own or any policy interventions are required to protect it.

Because of a blame game between developing and developed economies on the issue of $CO_2$ emission there is no clear cut consensus what and how to do for containing$CO_2$ emission. The developing and least developed economies are also over occupied on economic development without paying much heed to the environment. Hence, this kind of study will be helpful in present days' global scenario to devise the environmental friendly policies of economic developmentfor sustainable growth.The IPAT model and Environmental – Kuznets – Curve (EKC) which are employed in this study are relevant for policy issues. The results of this study would specifically guide which of the factors is crucial for checking the impact in terms of $CO_2$ release.

## 4. Organizationof study

This study is carried out by analyzing secondary data of World Bank available on its website and in various data bases of KDI School Library. The facilities available in KDI School are used for analysis of the data and writing the thesis.

All aspects of study are going to be presented in thisdocument. After explaining thesis problem and objectives in the preceding, the literature will be reviewed in next chapter. It will also throw light on the background literature and historical developments in these fields. The theories and environmental models developed by various authors will be discussed in details. The debate on Population–Environment– Emission; the Neo-Malthusian theory; IPAT model and its variantsshall be flashpoints in this chapter.

Third chapter will describe in details the methodology adopted for this study. The method of collection of data and its analysis will be described in this chapter.

The results of this study will be presented and explained in fourth chapter under various heads. The hypothesis will be tested and other findings will be explained.

The results will be discussed in the light of various theories and other empirical studies in fifth chapter. Seventh chapter is dedicated to conclusion. The Bibliography will follow thereafter.

# REVIEW OF LITERATURE

With the increase in environmental concern because of threats posed by indiscreet release of GHGsin general and $CO_2$in particular, anintense debate has begun about the role of economic development and populationpressurein global warming. Last two decades have witnessed heated debates amongst developed, developing and least developed economies in all climate change conferences. It has now become a blame game where all the three categories of economies are holding each other responsible for huge accumulation of $CO_2$ in the atmosphere.

The point of concern is that the developing and least developed nations are catching up the development to come out of the jaws of abject poverty. While, the most of the developed countries industrializedduring 18$^{th}$, 19$^{th}$ and first half of 20$^{th}$century when there was little attention on environmentaldegradation, the developing countries followed the suit in the second half of last century when the environmental concern became all pervasive. With the rise of ‘East of Asian Tigers’and emergence of China, the most of least developedeconomieshave started emulatingthem to cross the line of poverty. As a result, there has been a surge in economic activities on every part of the globe.

In addition to economic growth, another factor which is considered as detrimental to the environment is population pressure. Statistics show that there are as many as six times more people consuming earth’s resources than were present in 1830 AD. The population growth increased abruptly in developing and least developed economies after World War II.

However, in spite of the increased pressure on resources man has made efforts by technological advancements to increase the productivity in order to cater the demands and needs of burgeoning population. Had technological advancements not taken place Malthusian Essay could have become the reality.

The historical developments and evolution of various models and theories related to population – environment – development debate described in following heads.

**1. Population vs. Environment**

**2. Economic Development vs.Environment**

**3. Empirical models – IPAT model and Environmental Kuznets Curve**

**1. Population versus Environment**

**(a) Historical Background – early developments**

The idea of interrelation between population, environment and development is as old as the human civilization. It is documented by Heroditus[6], writing in the 5th century BC that there was a famine which lasted for 18 years (The History Book 1:22-23) because the population of Lydians outpaced the production (Thomas and Eugene, 1994). Seneca the Younger writing during the first decade of the Christian era observed a close relation between population and pollution in Rome.[7] He noticed pollution because of household cooking fires; increased traffic on dusty streets, and

[6]Heroditus writes that during this period the method of adjustment of the Lydians was to invent a number of games, including dice, and "to engage in games one day entirely so as not to feel any craving for food, and the next day to eat and abstain from games" (The History, Book 1:22) Eventually, because scarcities continued and conditions worsened, the King decreed that half the population should emigrate to Smyrna, the choice of movers and stayers determined by lot. Thus Heroditus explained not only population and resources, but also about the role of risk and uncertainty in human affairs.

[7] Lucius Annaeus Seneca, c. 4 B.C. - 65 A.D., the second son of the Roman educator and Author, Seneca the Elder, is considered the most brilliant thinker and writer of his time, the age of Nero.

burning of dead bodies. Baring these scanty references, the recognition of relationship between population and environment was limited in the earlier times.

The idea of a link between population and resources started developingwith more clarity from eleventh century onwards. In 1086, William- the Conqueror, commissioned an enumeration of the population and its landed wealth, recording the results in the Doomsday Book (the word "doomsday,")(Weeks, 1986). This accounting was instrumental in evolving the idea that there is a relation between population and resources.

**(b) Malthusian view point**

The populationresources link received a systematic attention when Malthus (1766-1834) wrote an Essay on 'the Principal of Population' in 1798. He said, "Geometric growth (exponential growth in modem parlance) in population would eventually outstrip the arithmetic growth (or linear growth) in the means of subsistence." In other words, unless population was kept in check, the obvious outcome would be perpetual misery and poverty. He was the first to state that there are limits of material goods which earth's resources can produce. Before that time earth's resources were considered to be inexhaustible. This idea of Malthus initiated the thought of preserving the resources for future. However, the tenets of Malthus expressed in the essay were refuted by the technological advancements in the production of chemical fertilizers, development of irrigation technologies, development of high yielding crop varieties which resulted in to higher production.

However, in the initial studies the systematic investigation of human-environment interrelations was generally missing. However, these early and primitive hints set the stage for the current state of affairs i.e. the investigation of environmental problems.

(c) **Neo-Malthusian view**

In the last century Dr. Paul Ehrlich wrote a book "The Population Bomb" in 1968. This book threw a light on the problems of expanding population. It gave rise to new era in the area of environmental movements. In his book he visualized famines, resource war, polluted oceans / water, accumulation of atmospheric GHGs and general degradation of the natural environment. In 1990 Dr Ehrlich along with his wife wrote another book titled as 'The Population Explosion' which was a follow up to his earlier book. He highlighted that increased productivity was brought by the green revolution and showed that industrialized agriculture productivity peaked in mid-1980s. Since then yield has fallen and population has continued to grow. He also explained how the farm practices coupled with chemical use have resulted into reduction in farm productivity. When the issue of population growth is discussed the industrialized nations held that the problem lies in third world countries where the most explosive growth exists. It is also the fact that many of the industrializednations have attained growth rate at or near to zero. The argument is valid only if the population is the only factor. However, the population dilemma is as much a problem of resources and consumption as it is of population. This book addresses this problem with a most important idea. This book explains that the impact of humans on the environment can be understood as the product of three separate factors.***"**The first is the number of people. The second is some measure of the average person's consumption of resources (which is also an index of affluence). Finally, the product of those two factors – the population and its per capita consumption- is multiplied by an index of the* *environmental disruptiveness of the technologies that provide the goods consumed. The last factor can also be viewed as the environmental impact per quantity of consumption. In short, Impact = Population x Affluence x Technology or I=PAT.***”**(Ehrlich and Ehrlich, 1990).

He further explains that population does not act alone in its effect on the environment because in developed countries though the population growth is low or zero yet they use a much greater percentage of world’s resources than the people of third world. He emphatically asserts that both the developed and developing world have contributed to the negative environmental impacts.

In their book they explain that there are three possible futures of humanity: the bang, the whimper and the alternative. By bang they mean a nuclear war which will result from the growing population putting pressure on natural resources. However, they further say that this possibility is very remote. The second term whimper would be the consequence of failure of life support systems ceasing to function because the earth will become over burdened with huge population. In this situation if the economy will become more localized the situation will become worse. The third term alternative would mean to halt population growth, conversion of economic system from one of growthism to sustainable with decreasing per capita consumption, and lastly adoption of environmental friendly technologies.

(d) **Population in Environmental Economics**

With the growth in population, the values of scarcity rent increase. It increases the price of environmental resources relative to the cost of labor. Consequently, the workers face lower salary problem whereas rent owners get higher benefits. The income distribution thus becomes more un-equal leading to increase in the number of poor (as the rent owners generally belong to high income groups) (O'Neill et al, 2001). As per this argument population growth increases distortions in the market place for environmental goods and lead to the misallocation of property rights. However, the impact of population on economic growth is still controversial. Hence, it is not possible to find a unidirectional casual relation between economic growth and environmental resources. However, the neoclassical population-development-environment model has some optimistic perspective because of international trade. According to Panayotou (1994) there are four points about international trade which offset the detrimental impact of population growth. These are: the trading in scarce resources (ecological capital); the import and export of new technologies (substitution argument); the specialization in less resource intensive production (comparative advantage argument of Ricardo); and the trading of less pollution-intensive or resource intensive intermediate ad final products. In nutshell, it can be said that population does not exert a negative impact on resources. This is true under the condition that neoclassical assumptions are verified (including efficient allocation of property rights for environmental sources, free trade and perfectly competitive markets).

(e) **Neo-classical Theories**

If the assumptions described in above passage do not hold good, the results of neo-classical model change altogether. This is where the Neo-Malthusian hypothesis makes its way. It claims that that there are limits to technological advancements and to economic growth. Meaning thereby, the population growth bound to cause environmental degradation.

This theory has its origin in 1960s and early 1970s when the books viz. 'The Population Bomb' by Paul Ehrlich and 'The Limits to Growth' by the Club of Rome were published. Their main theory was different from the Malthus's doomsday hypothesis, it was more focused on environment degradation i.e. the richer the people getthe worse are the effects on natural resources. It means when there is progress everywhere; the Neo-Malthusians see disasters; air pollution, the disappearance of habitats, the emptying of aquifers, the felling of forests and appearance of new disease. In nut shell the Neo-Malthusians see us advancing towards disaster as we progress.

The theory that population growth has negative impact on economic development and environmental resources is based upon the demographic idea of 'carrying capacity'. Itis defined as the maximum number of individuals that an environment can sustainwithout being depleted(Zaba and Scoones, 1994). Further increase in population beyond the limits of the carrying capacity is detrimental to the environment and to the preservation of natural resources. The concept of carrying capacity in case of earth and population has been applied by the social scientists. Cohen (1995a) has worked out that the Earth can support, roughly, 4 to 16 billion people. Some other workers Smil (1994) introduced the method to measure the 'carrying capacity' in terms of resources viz. food and energy.

However, recent studies have shown that the concept of carrying capacity is not of muchimportance in studying human populations. Cohen (1995b) justified this criticism by mentioning that somefactors like values (human choices), international trade of ecological capital and migration can affect carrying capacity. Neo-Malthusian proponents believe that these factors just help in delaying the problem of overpopulation but not solve it. The Neo-Malthusian position considers the 'carrying capacity model' still applicable to social sciences. It states the catastrophic impact on the environment and the economy by demographic increase, particularly in developing countries (O' Neill et al. 2001).

At the time of publication of *the Limits to Growth* by Club of Rome Meadows et al. (1972) the hypothesis of incompatibility amongst the population growth, economic development and the environment was tested in quantitative terms. It was estimated at that time that overpopulation would result in the exhaustion of non-renewable. However, the reality turned otherwise. None of the predictions came true. Instead, the Neo-Malthusians still continued their quest. The academicians are worried about the food security issues in developing countries (Brown et al. 1999). However, there is variance in the results of different authors in developing countries (Dyson, 1996).

Inrecent studies it was revealed that it is not the population of the poor and developing countries which is causing the environmental pollution,but is the economic growth which is responsible for high GHG emission. Molinas (2010) also proved empirically that Neo-Malthusian hypothesis i.e. incompatibility between population and environment does not hold true in case of India.

### 2. Economic Development versusEnvironment

This section will through a light on the effect of economic development on environment. According to Georgescu-Roegen (1971) and Meadows et al. (1972)economic growth in terms of increased production and consumption requires large resources and huge inputs of energy; and generate large quantities of waste (by-products) in addition to goods and services. Excessive extraction of natural resources, accumulation of waste in the environment and increase in concentration of pollutants results into degradation of environmental quality which ultimately results into decline into human welfare despite increase in income (Daly, 1977). This also imperils the economic activity.  Hence, some are of the view that to save the environment and economic activity from itself, the economic growth must cease and the world should follow the steady-state economy (Panayotou, 2003).

Another school of thought explains that the fastest road to environmental improvement is along the path of economic growth. It argues that with the increase in incomes there is increased demand for goods and services which are less material intensive; as well as demand for improved environmental quality. It leads to adoption of environmental protection measures. Beckerman (1992) says, “The strong correlation between incomes, and the extent to which environmental protection measures are adopted, demonstrates that in the longer run, the surest way to improve your environment is to become rich.”

Yet some others are of the opinion that the relationship between economic growth and environmental quality is not fixed along development path of a country. It changes from positive to negative as a country reaches a level of income at which people demand and afford more efficient infrastructureand cleanenvironment (Shalik and Bandyopadhaya, 1992). This model was postulated by Kuznets (1965) through his ‘EnvironmentalKuznets Curve’ It explains that at initial stages of development, the quantity and intensity of environmental damage are limited to subsistence economic activity and to small quantities of wastes. As industrialization takes off, both the resources depletion and waste generation accelerates. At higher stages of development, there evolve more efficient and environmental friendly technologieswhich result in a steady decline of environmental degradation.

The modern neoclassical growth model is based upon the assumption that there is trade-off between per capita consumption of material goods and number of children in a household (Barro and Sala-y-Martin, 1999). It means there is tradeoff between the quality of the environment and consumption when environmental goods[8] are introduced to the model. The basic concept behind the environmental economics models is that of scarcity. The prices are expected to go up as the resources are scarce. It gives a chance to the producers to introduce less resources intensive technologies and to enhance technological progress. The price of environmental goods in terms of financial assets is called as 'scarcity rent' (O'Neill et al, 2001). This rent should increase over the time more than the financial interest rate. If it is not so the renters' withdraw resources and invest in profitable ventures. It is because of this that the owner of the stock conserves the supplies for the future to maintain higher prices and not introducing large amounts of resources in to the market (Pearce and Turner, 1990).

The Neoclassical model also asserts that the demand for environmental quality rises when income increases (Panayotou, 1994). It means that economic growth does not put negative pressure on environmental resources as the people become more and more environmental conscious and demands more environmental protection. It is the result of the hypothesis of low elasticity to income of the demand for basic goods. It means as the income of consumers go up and up they demand marginally fewer and fewer primary products (connected to the environmental resources) such as food. Contrary to that demand for environmental protection and for

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[8] Environmental goods are considered both in terms of non-renewable resources and environmental loss ( Pearce and Turner, 1990)

preservation of scarce resources goes up. This preservation of scarce resources introduces the definition of ‘environmental sustainability’. This concept is connected to the discount rate. The discount rate is typical of the cost benefit models and can be described as the rate by which the value of natural resources has to be multiplied to verify their depletion across intergenerational transfer (Pearce and Turner, 1990).The higher the discount rate is, the more the value of environmental goods decline and hence, the less environmental sustainable is the economy (O’Neill et al, 2001). It shows that the economic growth under perfect market is not harmful for the preservation of natural resources.

## 3. Empirical Models of Environment–Economic–Population studies

### A. IPAT model

According to O’Neill et al. (2001), the tool of choice in estimating the direct effects of population growth has been the impact identity. It expresses total environmental impact as the product of population and per capita environmentalimpact:

**Impact = population x impact per capita**

Here, Impact is taken either as utilization of a natural resource or emission of a pollutant. Impact per capita is a function of economic output and impact per unit of output produced:

**Impact =population X output per capita Ximpact per unit per out put**

In economic accounting, the value of output equals total income, so output per capita is referred to as “affluence.” Impact per unit of output conventionally referred to a “technology,” depends upon the nature of production process employed. By combining all, the most common demographic impact identity is the **I=PAT** equation:

$$I(t) = P(t) \times A(t) \times T(t)$$

Where I is natural resources utilized or pollution generated (impact); P is population; A is per capita output (affluence); T is natural resources used or pollution produced per unit of output (technology); and the ‘t’ is the time dimension.

Hence in terms of $CO_2$ emission, the equation might be:

$CO_2$ **emission = population X GDP per capita X** $CO_2$ **emission per unit of GDP.**

This identity was developed in early 1970s during the course of a debate between Barry Commoner, who argued that environmental impact is due to the technologicalchanges in production technology after post World War; and Paul Ehrlilch and John Holdren (1971) who argued that all three factors were important and emphasized the role of population growth. After a debate both Commoner et al. (1971) and Ehrlich and Holdern (1971) then formalizedthe I=PAT equation to make quantitative arguments on the relative importance of the factors contributing to pollution.

Subsequently, a variety of forms of the I=PAT identity were used to analyze a wide range of issues, includingautomobile pollution (Commoner, 1991), fertilizer use (Harison, 1992), energy (Pearce, 1991) and air quality (Cramer, 1998) among others.

The I=PAT identity also illustrates an important consequence of the multiplicative relationship between driving forces as each variable amplifies changes in any other. In other words, a given change in technology may have only small effect on the environment in a society with a small, low income population, while the same change would have a much greater effect in a populous, affluent society. Likewise, a given increment in population would have a much greater impact in affluent societies than in low-income countries, assuming the levels of technologies are similar.

**Decompositions in IPAT model**(**Bongaarts, 1992**)

It is also possible to quantify the relativeimportance of each of the driving variables. It can be done by decomposing historical or projected trends in environmental impacts into contributions from trends in each of the variables. The transformationcan be made by taking logarithm of both sides of the equation or by differentiating and expressing the terms of growth rates so that I=PAT becomes:

**I' = P' + A' + T',**Where prime notation denotes continuous growth rate over a period of time.

Normalization of this decomposition allows comparison between the variables. The standard normalization for decomposition of growth rates is to divide all the growth rates by the growth rate of impact that is :

$$1 = P'/I' + A'/I' + T'/I'$$

It helps in assessment of results in terms of percentage contribution of each variable. The growth rate decomposition methodology has been applied by several researchers to the studiesin GHG emissions (Bongaarts, 1992).

However, growth rate decomposition method suffers from a number of inherent weaknesses (O'Neill et al. 2001). First major issue is offset problem. If one of the variables on right hand side reduces, it will offset the contribution of one of the growing variables and the third variable will be left accounting for large proportion of total environmental impact. This problem arises in case of GHG emission trends.

Second problem is heterogeneity bias. The demographic heterogeneity may bias decomposition in two ways. First source of bias arises as the population is also related to per capita impact (Lutz, 1993).In the case of global carbon emissions and population growth; because per capita emissions are lowest where population growth is highest, decomposition at the global level overstate the contribution of population growth.

Next problem is absolute versus relative change in the variables. It is argued by some workers that it is the absolute amount of pollutant emissions that damages the environment and not annual growth rates. (Keyfitz, 1992).

**Alternative forms of the IPAT equation**

The equation in the form of I=PAT quickly became established as the norm and has been used and cited by many organizations and individual people ever since. However, in more recent times, various alternative formulations of the equation have been proposed. Dietz and Rosa (1994) gave a stochastic reformulation of the impact equation which they claimed facilitates the application of social research statistical tools to studies on I=PAT. Their formulation is I = aP b A c T d e. They define A and T as per capita economic activity and the impact per unit of economic activity respectively; a, b, c, and d are parameters and e, a residual term.

The equation "suggests that, aside from important choices about future birth rates, the only ways a rational individual can reduce her environmental impacts are by reducing wealth or using more efficient technologies. But of course, per capita impacts also depend upon modifying behavior)" (Schulze, 2002). Schulze (2002) proposes modifying the formula to I=PBAT, which calls attention "to the many behavioral choices that are immediately available to all individuals". He points out that affluence and technology do not guide behavioral decisions. He exemplifies that a wealthy person can only use the most efficient devices. But the environmental impact of that individual still depends upon whether the person is a profligate consumer or not.

Willey D. (2000) observed that consumption is influenced by lifestyle and organization. Better organizations in rich countries could lead to a reduced per capita consumption, but same type of organizations in poor countries might lead to a huge increase in consumption. So he proposed changing the impact equation to I = PLOT (population, lifestyle, organization, technology). This theory mainly explains the incompatibility between demographic growth and preservation of the environment in developing countries. The present day environmental crisis is believed to be resulting from differences between growth rates of population increase and the regeneration of the material base for development. In this way the environmental impact is defined in terms of aggregated quantities. It results into natural resource scarcity like that of biodiversity, water resources, capacity to absorb greenhouse gases, etc. Also the large quantitative aggregates are blamed for the crisis; still some others blame the level of economic growth; and the Neo-Malthusian environmentalistsblame the population increase.

IPAT equation recognizes that the impact of a human population on the environment is basically the product of the population's size (P), its affluence (A), and the environmental damage inflicted by the technologies used to supply each unit of consumption (T). Sometimes, because of the difficulty in estimating A and T, per capita energy use is employed as a surrogate for their product. Some equate T with impact per unit of economic activity, and for others T is a rather fuzzy category covering all sources of variation apart from population and affluence.

The impact equation was introduced in a paper by Ehrlich and Holdren in 1971 in the form I = P. F, where F is a function that measures per capita impact.In this equation technological change has multiplier effect on population size and the wealthiest of the population. There is some truth in this equation.Ascounties get richer and more populous, they consume more resources especially in the earlier phases of economic growth.

**B. Environmental – Kuznets- Curve (EKC)**

The Environmental-Kuznets-Curve (EKC) is a relationship between environmental quality and economic development. It explains that various indicators of environmental degradation tend to get worse as economic growth occurs until average income reaches a certain point over the course of development (Shafik, N. 1994). Although thismodel is of great debate, some evidence supports the claim that environmental health indicators, such as water and air pollution, show the inverted U-shaped curve (John Tierney, 2009). It is observed that this trend occurs in many of the environmental pollutants, such as sulfur dioxide, nitrogen oxide, lead, DDT, chlorofluorocarbons, sewage, and other chemicals previously released directly into the air or water.

However, there is scarcity of the evidence that the relationship holds true for other pollutants, for natural resource use or for biodiversity conservation(Mills and Waite, 2009). For example, energy, land and resource use do not fall with rising income. It is seen that in developed countries the ratio of energy per real GDP has fallen where as total energy use is still rising. Another example is the emission of many greenhouse gases, which is much higher in industrialized countries.

In empirical studies, the Kuznets curves have been found true for some environmental health concerns (such as air pollution) but not for others (such as landfills and biodiversity). The proponents of the EKC argue that this does not necessarily invalidate the hypothesis – the scale of the Kuznets curves may differ for different environmental impacts and different regions. If the search for scalar and regional effects can salvage the concept, it may yet be the case that a given area will need more wealth in order to see a decline in environmental pollutants. Contrary to that, a thermodynamically improved economics suggest that outputs of degraded matter and energy are an inescapable consequence of any use of matter and energy (so holds the second law); some of those degraded outputs will be noxious wastes, and whether and how their production is eliminated depends more on regulatory schemes and technologies at use than on income or production levels. One view is that the EKC suggests that "the solution to pollution is more economic growth;" In second view, pollution is seen as a regrettable output that should be reduced when the benefits brought by its production are exceeded by the costs it imposes in externalities like health decrements and loss of ecosystem services.

**Criticism of Environmental- Kuznets- Curve**

The Critics of Environmental- Kuznets- Curve emphatically argue that the

United States of America has still not attained the income level necessary to contain certain environmental pollutants such as carbon emissions (it has yet to follow the EKC trends). For other pollutants like sulfur dioxide, production seems to coincide with a country's economic development and at a certain threshold level of income a mitigation of environmental damage occurs. This meansthat economic growth without much institutional reforms does not accomplish the so called environmental improvement. It appears that with GDP growth, government policies are strengthened and there is a rise in the demand for improved environmental quality. It is also possible that under such situations with stringent regulations in developed countries shift the production to less-regulated, poorer countries, thus, causing more pollution. If it is true, the total size of the negative externalities of production remains the same or is larger, though in the wealthier country an EKC appears to have been obtained.This is a reason that Environmental- Kuznets-Curves (EKC) have been found to be applicable to only certain types of pollutants (Yandle et al. 2000). Yandleet al. (2000) argue that the EKC does not apply to $CO_2$ emission because it has global effect. The most the pollutants create localized problems like lead and sulfur because of which there is a greater urgency and response to taking appropriate measure. As a country develops, the marginal value of cleaning up such pollutants makes a large direct improvement to the quality of life. Hence, reducing carbon dioxide emissions does not have a much impact at local level. Hence, people are least bothered about its containment. Thus, even in a country like the US with a high level of income, carbon emissions are not decreasing in accordance with the EKC(Yandle et al. 2000).

Levinson(2000) states that researchers disagree with the shape of the EKC curve in longterm. Some researchers regard the traditional "inverse U" shape as actually being an "N" shape, describing that pollution increases atthe early stages of development of a country, decreases after a threshold GDP is reached, and then begins increasing as national income continues to increase. However,this theory is also debatable.It is important because it poses the valid question that whether pollution actually begins to decline after an economic threshold is reached or whether the decrease is only in local pollutants and pollution is simply exported to poorer developing countries (Levinson,A.2000). In nutshell, he concludes that the environmental Kuznets curve is insufficient to support a pollution policy.

Arrow et al.(1995) argue that pollution-income increasefrom agrarian economies (clean economy) to industrial economies (pollution intensive) to service economies (cleaner) would appear to be false if pollution increasesdue to higher levels of income and consumption. The great difficulty with this assumption is that it lacks predictive power as it is highly uncertain to explain how the next phase of economic development would be characterized.

According to Panayotou (2003), while using a model in population-growth-environment there are five important questions. First, does inverted U shaped - Environment Kuznets Curve, which is the relationship between income and environmental degradation, actually exists, and if so how robust and general is it? Second, what is the role of population growth, income distribution, international trade and time-and-space-dependentvariables? Third, how relevant is a statistical relationship estimated from cross-country or panel data to an individual country's environmental trajectory and to the likely path of LDCs and developing economies? Fourth, what are the implications of ecological thresholds and irreversible damages for the inverted-U-shaped relationship between environmentaldegradation and economic growth? Can statistical relationship be interpreted in terms of carrying capacity, ecosystem resilience and sustainability? Finally, what is the role of environment policy in explaining the shape of the income-environment relationship and lowering the environmental price of economic growth and ensuring more sustainable out come?

# RESEARCH METHOD

Various aspects of methodology adopted in this study are described as under:

**1. Selection of variables**

The literature is replete with the empirical studies on assessment of effects of population, economicdevelopment and technological advancementson environment. Various models have been designed and methodswere evolved to assess the impact on environment with great precision and accuracy. Under ideal situations, the environmental impact can be assessed by taking into accountindependent parameters / factorslike anthropogenic pressure, economic activity, animalistic factors, populationgrowthand natural processes over a period of time. There is a great deal of difficulty in identifying the reliable variable which could predict the environmental damage with maximum precision. The situation becomes more complicated asthere exists a complex relationship among various components of the environment and the factors influencing them.

Keeping in view above concernspresent days' empirical models usually take into consideration the environmental impact indicators (like GHG emissions; pollutants etc.) and per capita income; or sometimes composite indices of environmental degradation. The common independent variable of themost of the models is income per capita or income data on purchasing power parity or incomes at present exchange rates. Different studies control different variables such as population density, openness to trade, income distribution and geographical and institutional variables. They are estimated using data for a particular period of time. There have been efforts to study various theoriesunderpinning the environment – income-population relationship and to decompose the relationship into its constituent scales, composition and abatement effects.Stern (1998) concluded that there has been no explicit empirical testing of models and still we don't have a rigorous, robust and systematic model for this analysis.

In this complex situation, simple model is that which takes into consideration the impact of population and economic growth on quality of environment or availability of natural resources.In other words, the impact of population growth on GHG emission consists of impact on consumption demands that give rise to demand for energy (fossil fuels), agricultural products and goods whose production is associated with depletion of natural resources.

It is true that it is not easy to measure the environmental impact due to human interference (population) and economic activity (economic development)with greatprecision and high accuracy (Cole and Neumayer, 2004). It is because of non availability of effective assessment models, methods and actual data pertaining to underlying factors.In this situation, $CO_2$ emission is considered as one of the reliable and objective estimate of environmental degradation. It is because of the reason that carbon emissions are connected to burning of fossil fuels i.e. use of natural resources; and release of co2 by direct or indirect human activities (Dyson, 2005). Secondly, carbon emissions are the one of the reliable indicators of economic growth (Bongaarts, 1992). In nutshell,$CO_2$emissions may depict the depletion of natural resources, the extent of anthropogenic pressure and bye product of economic activities.

### $CO_2$ Emission Intensity as an Indicator of Technology (T)

In empirical studies on environment '$CO_2$Emission Intensity' has widely been used as the indicator of technology.It isdefined as the amount of $CO_2$ generated by one unit of GDP. In other words, it is the amount of pollutant generated by one unit of GDP.  It is a variant of absolute quantity of $CO_2$ emission. This variable helps in understanding the role of technology in economicdevelopment. For instance, high $CO_2$ emission per unit of GDP indicates primitive and outdated technologies. On the other side low emission per unit GDP indicates advanced and environmental friendly technologies. Hence, in the present study the $CO_2$ emission intensity is taken as an indicator of technological advancements.

Hence, population growth, GDP per capita and $CO_2$ emission intensity are used as independent variables to calculate the impact.Another advantage of using population, GDP per capita, $CO_2$ emission intensity for assessment of impact is that the data is available in absolute numbers with great accuracy and precision.

2. **Selection of Models for Data Analysis**

As has been discussed earlier this is a two step study. In the first step, the most harmful driver of $CO_2$ emission is identified out of above three parameters. Then the nature and pattern of the driver is studied along the developmental path of a country. In order to generalize the pattern, all three categories of the economies viz. developed, developing and least developed are subjected to examination.

Two models which are used in this study are described in as under:

**A. IPAT model**

The decomposition identity developed byBongaarts (1992), I' = P' + A' + T' is used in this study. He was the first to use this model for assessment of environmental impact by taking $CO_2$ emission as pollutant. He used additive identity rather than multiplicative form of IPAT (the details discussed in previous section). This allows standardization of all variables on the right hand side in terms of annual impact growth by dividing P’, A’ and T’ by I’. Because the relative percentage can be calculated in the equation, it makes possible to assess which of the three variables is more harmful or contributes more to the total impact (I).The variables P, A and T are expressed in terms of continuous average growth rate over a period of time.

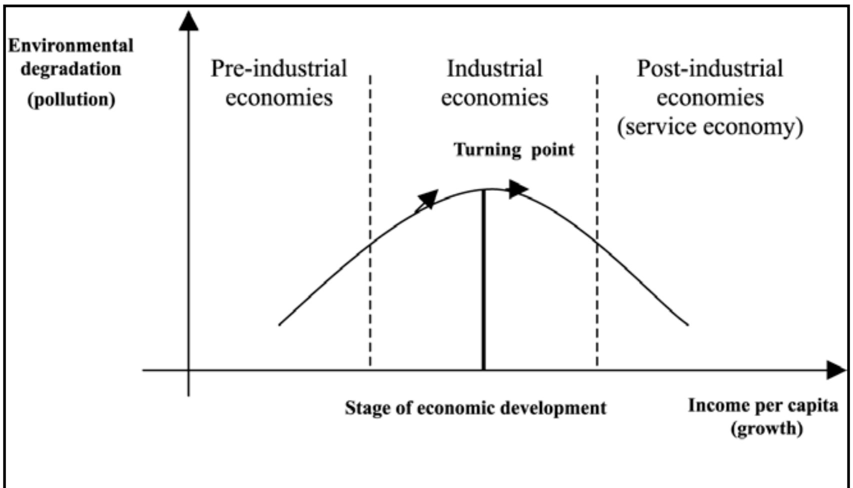
In above equation I’ represents pollutant emission; P’ for Population growth; A’ for affluence depicting economic growth per capita i.e. GDP per capita; and T’ stands for intensity of the impact on economic growth expressed as ratio of impact ($CO_2$ emission) on GDP.

It is because of this very property of the model that it was employed in similar studies by Molinas(2010); and Blodgett and Parker (2010) among others.

**B. Environmental- Kuznets – Curve (EKC)**

A large number of empirical studies have been carried out for pollutants like $SO_2$ and $NO_2$ etc, however, the most of the researchers are of the opinion that Environmental – Kuznets – Curve (EKC) does not fit in case of GHGs, more precisely for $CO_2$ as a pollutant. They exemplify USA and other developed countries where EKC does not hold good. However, in this study a large number of countries from all parts of the world are subjected to analysis to examine the relationship between economic developments and $CO_2$ emission.

In principles the Environmental- Kuznets-Curve follows the trajectory as under:



**Source:** Panayotou (1993)

The data will be subjected to this model to examine whether $CO_2$ follows this trajectory or not.

3. **Selection of Economies**

This is a comparative study of developing, developed and least developed economies of all parts of the world. There is no specific criterion for the selection of countries among these categories. However, a general rule is that the most developed countries; the fastest growing economiesamongst developing countries; and the fastest growingnations among least developed nations are selected by taking seven from each group. The group of developed economies includes United States of America (USA), United Kingdom (UK), France, Germany, Japan, Canada and Italy. Among developing economies, the fastest growing economies selectedare: Brazil, Russia, India, China, South Africa, Indonesia and Malaysia. In the category of Least Developed Economies (LDCs) the countries included are: Bangladesh, Nepal, Kenya, Liberia, Madagascar, Malawi and Rwanda. Thecategories are defined as per the definition of United Nations Organizations.

## 4. Data Collection

### (a) Source of Data

Secondary data is retrieved from the Word Bank data base available in the library of KDI School of Public Policy. The data is available on website:**http://data.worldbank.org/**

### (b) DataCharacteristics

The data on total population, GDP and $CO_2$ emission is collected from the years 1971 to 2007 for the countries under reference. The Populationis expressed in absolute numbers; GDP in dollars at constantprices in the base year 2000; and CO2 emission in Kilo Giga Tones (Kgt).

## 5. Data Analysis

The Data is analyzedon the analogy of Molinas (2010); Blodgett & Parker (2010); as per Environmental – Kuznets – Curve.

### (a) Calculation of continuous Average Annual Growth Rate of the variables

As has been stated earlier, the additive form of IPAT model is used in this study which measures the Impact on the basis of continuesgrowth rates of population, GDP per capita and $CO_2$ emission intensity. Hence, the average annual growth rates of Population, GDP per capita and $CO_2$emission intensity arecalculated from the year 1971 to 2007. Thiscomplete period is divided into equal intervals of 5 yearsi.e. 1971 to 1975; 1976 to 1980; 1981 to 1985; …. and so on, up to 2000 – 2005. Last intervalistaken up of two years i.e. 2006 & 2007. The percent annual growth in each interval is calculated by simple mathematical derivations. Theaverage of all the intervals is taken as the ContinuousAverage Annual Growth Rate from 1971 to 2007. $CO_2$ emission intensity is calculated by dividing total $CO_2$ emission (Kgt) by GDPcorresponding to relevant time and ismultiplied by 1,000,000 in order to get workable/ manageableratio.

**(b) Assessment of total Impact (I')**

After calculating average annual growth of Population (P'); average annual growth of GDP/ affluence (A'); average annual change in $CO_2$ emission intensity (T'), the total impact is measured by adding all variables. i.e. I'=P'+A'+T'

**(c) Assessment ofpercentage of each variable in total impact (I')**

After calculating total impact 'I' the percentage contribution of each variablein total impactis calculated by simple mathematics.

**(d) Environmental-Kuznets-Curve**(EKC)

A relationship between total $CO_2$ emission and per capita GDP from 1971 to 2007 is depicted in EKC.

# RESULTS

This sectionis going to presentthe results obtained in the study. Country wisereal time data on population (absolute numbers), GDP (constant 2000 dollar prices), $CO_2$emission (Kgt) and $CO_2$ emission intensity ($CO_2$emission divided by GDP and multiplied by 1,000,000) isanalyzedand described as under:

For the sake of convenience the results are presented in following heads:

A. Status of $CO_2$ emission, economic growth (GDP per capita) and population.

B. Pattern of $CO_2$ emission intensity (indicator of Technology)

C. Results of IPAT model

D. Relations as found in Environmental- Kuznets-Curve

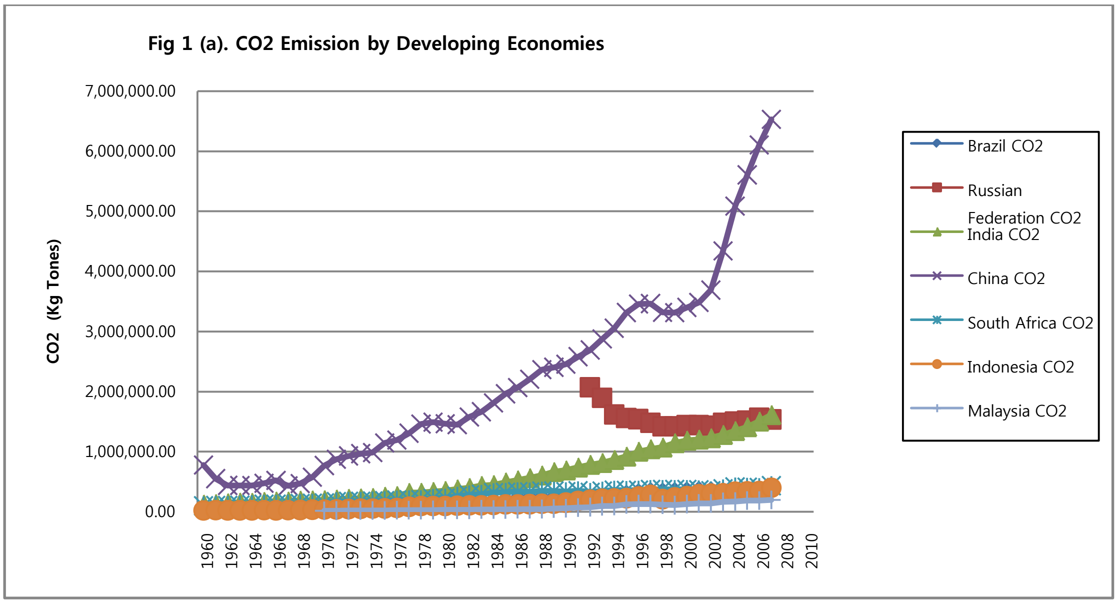
A. **Status of** $CO_2$ **emission, economic growth (GDP per capita) and population**

1. **Status of** $CO_2$ **emission**

Total$CO_2$ emitted (Kgt) from 1971 to 2007 by 21 countries of developing, developed and least developed category is depicted in Fig. 1(a), Fig. 1(b) and Fig. 1(c). It is evident that up to the year 1970 total emission was not very high in all three categories of the nations. The decade 1970s to 1980s saw a moderate increase in all countries. The status of $CO_2$ emission is discussed category wise as under.

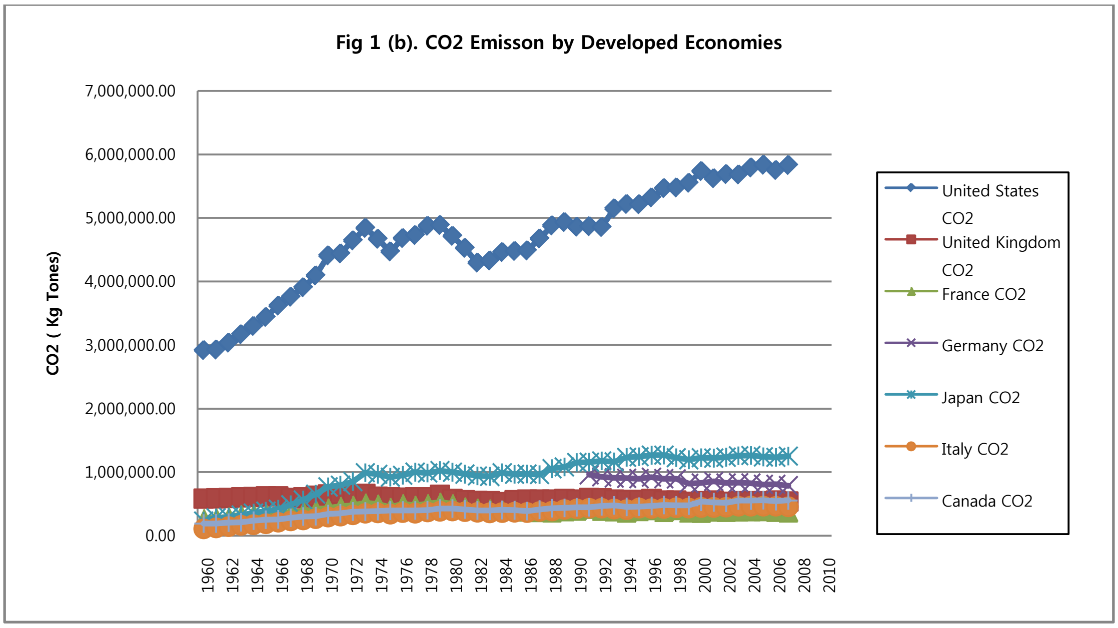
**a)**$CO_2$**Emission in Developing Economies**

China is the highest emitter among developing nations since 1960s. From the year 1975 to 1995, though there is relatively fast growth of emission yet, after 1995 it is abruptly high. India’s emission picked up after 1990s, however, total emission is relatively lower than China. Russia has shown downward emission trends after 1990. Brazil, South Africa, Indonesia and Malaysia all are showing moderate trends of emissions (Fig. 1 (a)). The average annual growth rate of $CO_2$ emission is highest in case of Indonesia which is 6.50 % followed by China (5.76%), then Malaysia (5.73%), India (5.33%), Brazil (3.47%), South Africa (2.73%) and Russia (-0.67%)(Table 4).



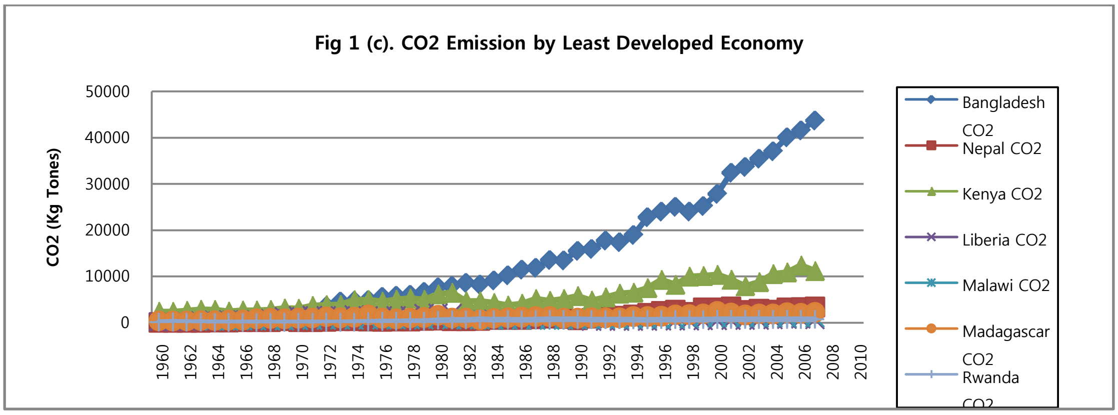

**b) $CO_2$ emission by Developed Economies**

Amongst developed nations USA is the largest emitter since 1960s. Up to 1975 the USA used to emit at the increasing rates. After that the rate of emission was undulating. The emission trends of Japan are also on increasing rates albeit not very high speed. Three developed countries of Europe viz. UK, France and Germany have contained the emission and are showing the downwards trends. The emission of Canada is also increasing (Fig 1 (b)). Having a look over average annual growth rate of $CO_2$ emission Canada has highest rate of 1.64 %, followed by Japan (1.31%), USA (0.86%), Italy (0.76%), UK (-0.94%), France(-1.01%) and then Germany (-1.82%) (Table 4) It is important to note that this growth is much below 1.64%.




## c)$CO_2$Emission by Least- Developed (LDCs) Economies

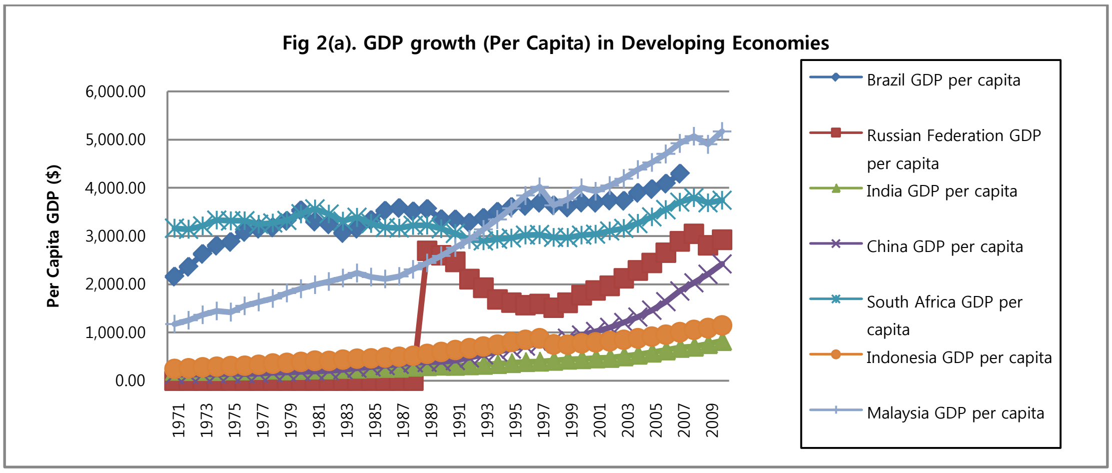
In the categories of Least Developed Economies, Bangladesh has been the highest emitter since 1980s followed by Kenya. After 1990s the emission by Bangladesh and Kenya increased substantially (Fig 1 (c)).The average annual growth rate of $CO_2$ emission is highest in case of Nepal which is 8.96%, followed by Rwanda (7.71%), Madagascar (6.79%), Bangladesh (6.00%), Kenya (2.58%), Malawi (2.23%) and then Liberia (-0.61%) (Table 4). It is evident from the table that this rate is above 5 % for the most of LDCs understudy.



## 2. Status of Economic Growth (Affluence) in terms of GDP per capita

### a)Economic growth in Developing Economies

Per capita GDP of Malaysia, Brazil and South Africa remained high since 1970s. Per capita GDP of China increased substantially after 1990s. India still remains at the lowest in terms of per capita GDP (Fig 2(a)). As for as average annual growth rate of GDP is concerned China exhibited remarkable GDP growth rate of 9.38% since 1971 followed by Malaysia (6.06%), Russia (5.55), Indonesia (5.31%), India (5.23%), Brazil (3.79%) and South Africa (2.49%) (Table 4).China started attaining high GDP growth in 1980s. After 1990s it was an abrupt growth rate. After the year 2000 China superseded all the economies of the world. In terms of total GDP, China and India have the highest total GDP.

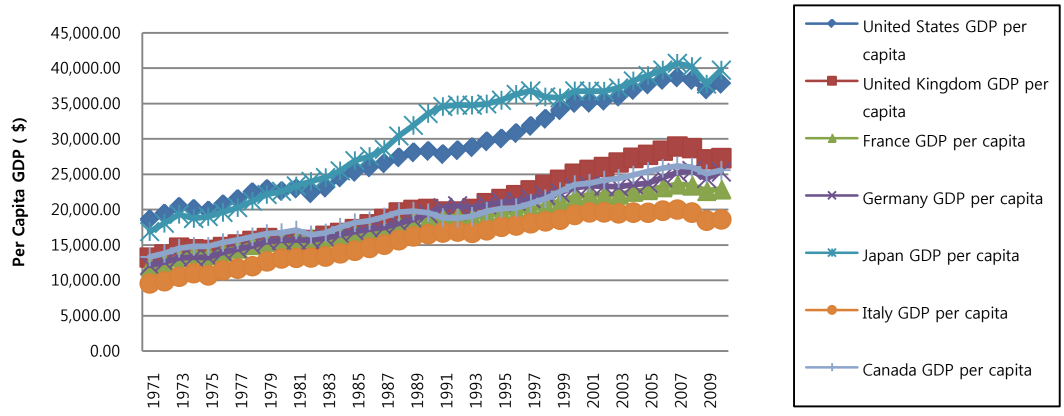



### b) Economicgrowth in Developed Economies

Among developed economies USA and Japan maintained highest GDP since 1970s.It is interesting to note that the shape of the curve is more or less similar in all the developed nations. All the seven economies were badly affected between the year 2005 to 2009 (Fig 2 (b)). The average annual growth rate of GDP is highest in case of

Canada which is 2.76 % followed by USA (2.65 %), Japan (2.63%), UK (2.24%), France (2.15%), Italy (1.89%) and then Germany (1.52 %). It is observed that the average annual growth rate of these developed economies remained between 1 to 3%.(Table 4).

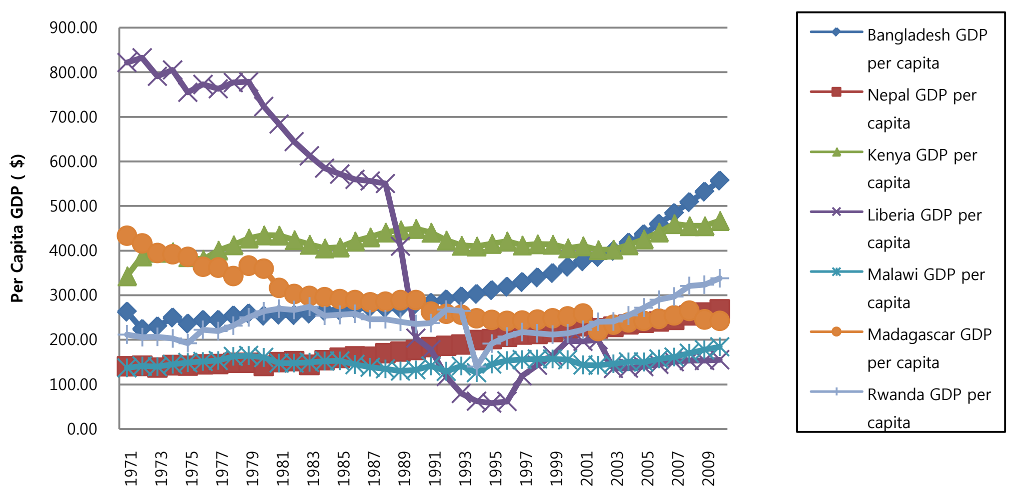
Fig 2 (b). GDP growth ( per capita) in Developed Economies




### c) Economic growth in Least- Developed (LDCs) Economies

The trends of economic growth in most of LDCs are erratic. Only Bangladesh and Nepal have shown gradual and consistent increase in their income (Fig 2(c)).The average annual growth rate of GDP per capita is highest in case of Liberia which is 5.15 % followed by Bangladesh (4.17%), Kenya (3.97%), Malawi (3.46 %), Nepal (3.15%), Rwanda (2.97%) and then Madagascar (2.09%) (Table 4).

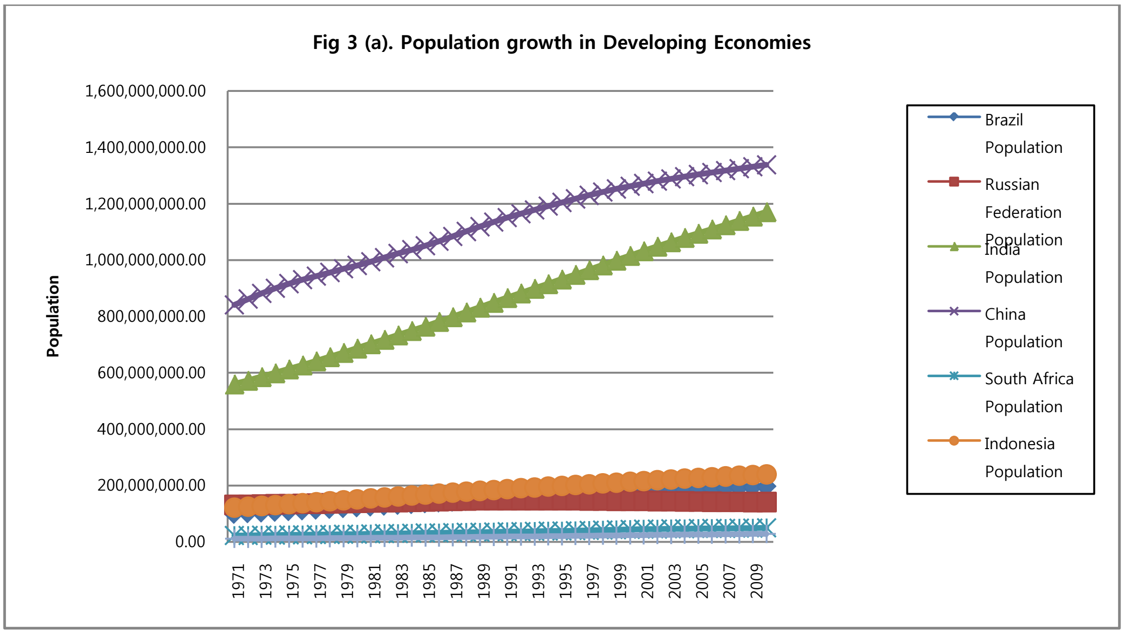
Fig 2 (c). GDP growth ( Per Capita) in Least Developing Economies



### 3. Statusof Population Growth

#### a) Population growth in Developing Economies

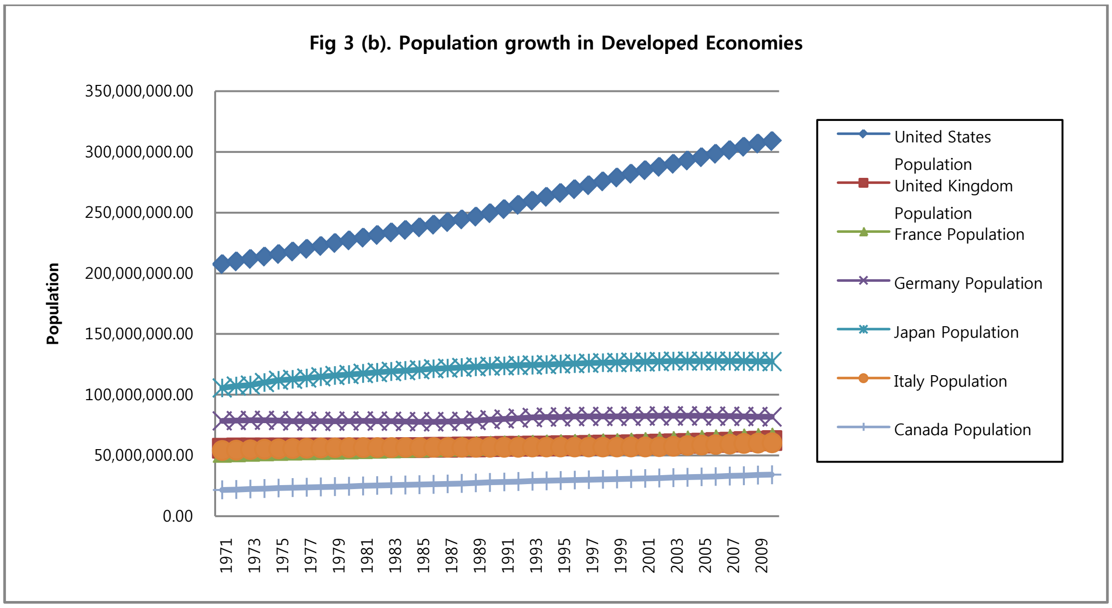
The population in absolute termsremained highest in China followed by India (Fig 3 (a)). However, amongst developing countries in reference, average annual growth from 1971 to 2007 is 2.05% in case of Malaysia followed by 1.71% in case of South Africa, then 1.60% for India, 1.48% in case of Indonesia and Brazil and 1.00% in case of China. The growth rate of population in case of Russia is negative (Table 4). The data also reveals that in developing countries the average annual growth remained mostly between 1 to 2%.




#### b) Population growth in Developed Economies

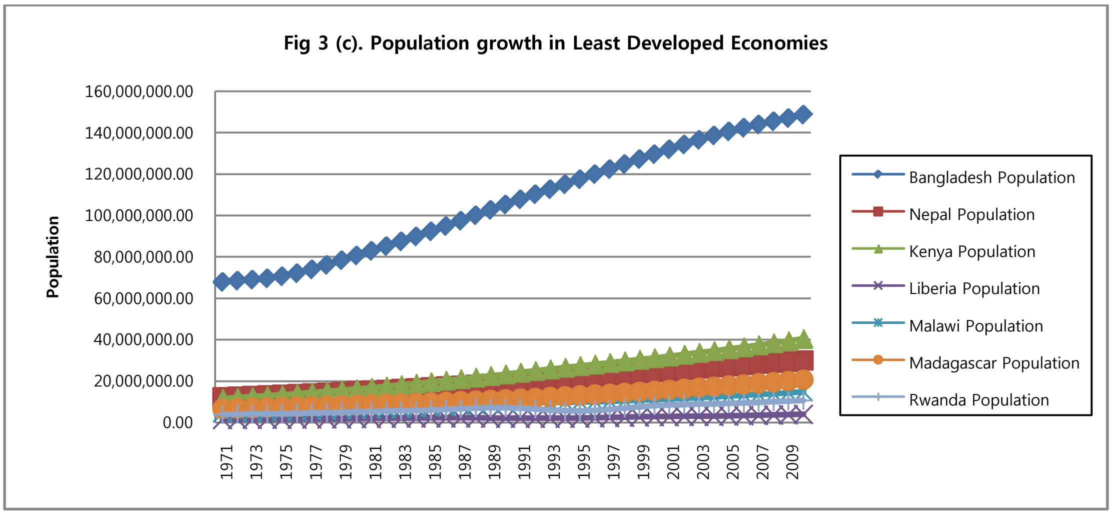
In absolute terms the magnitude of population remained highest in USA followed by Japan since 1971(Fig 3 (b)). However, in terms of average annual growth rate Canada is having highest growth rate of 0.97% followed by USA (0.86%), France (0.47%), Japan (0.41%), Italy (0.28%), UK (0.24%) and then Germany

(0.09%)(Table4). It is evident from the table that the average annual population growth remained below 1 % in the developed countries under study.




### c) Population growth in Least- Developed (LDCs) Economies

In terms of absolute numbers thepopulation of Bangladesh remained highest since 1971. Since late 1980s the population of Nepal was next highest, however, after that Kenya superseded Nepal (Fig 3 (c)). With regard to average annual growth rate Kenya has the highest rate at 2.78% followed by Malawi (2.60%), Madagascar (2.51%), Rwanda (2.43%), Liberia (2.35%), Nepal (1.98%) and then Bangladesh (1.81%). It is also evident that barring Bangladesh and Nepal the growth rate of all other LDCs is above 2% (Table 4).

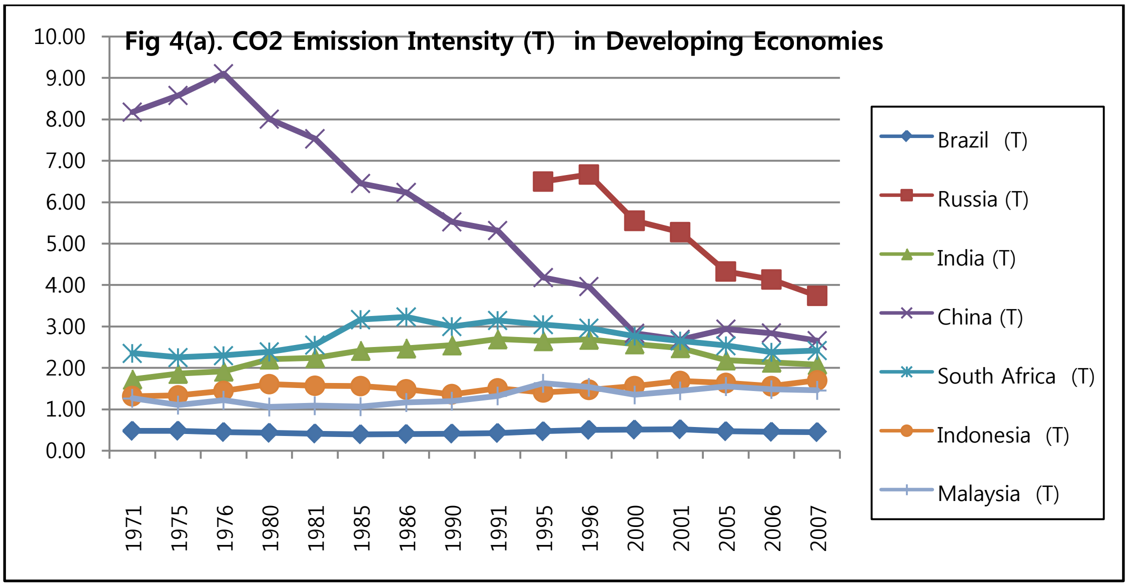


B. **Pattern of** $CO_2$ **Emission Intensity ( Indicator of Technology)**

This variable is calculated by dividing total $CO_2$ emission by GDP corresponding to a particular year. It denotes the pollution produced by one unit of GDP. The pattern observed from 1971 to 2007 is depicted in following graphs.

**1. Pattern of** $CO_2$**Emission Intensity in Developing Countries**

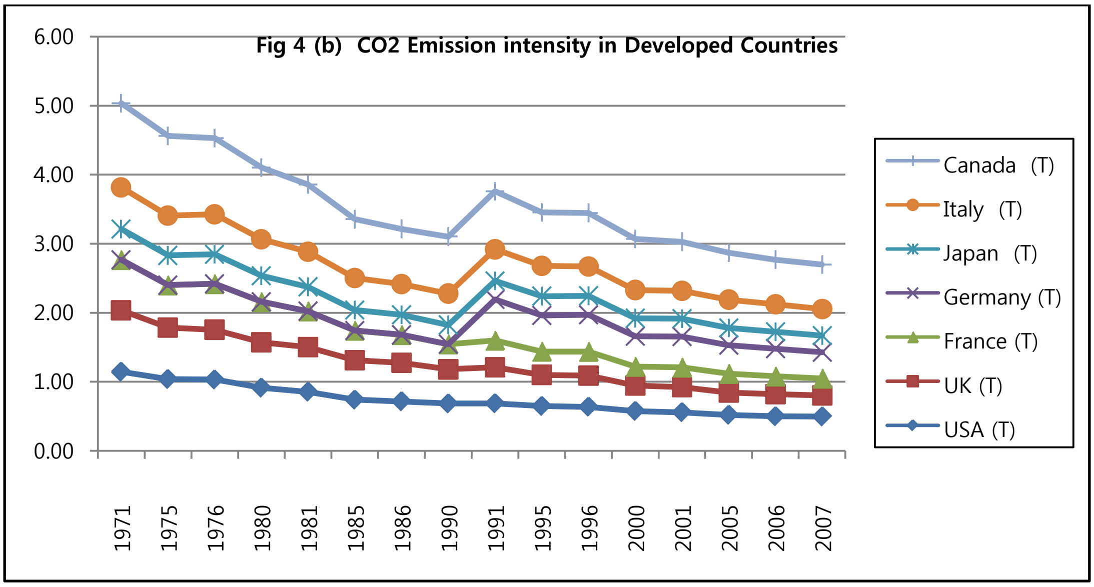
As is evident from the Fig 4 (a) $CO_2$ emission intensity of Brazil has been the lowest indicating production of lesser $CO_2$ per unit of GDP. Chinese emission intensity has been highest since 1970s till the year 2000. However, in terms of annual growth rate Chinese emission intensity has been reducing at a rate of -2.62% from 1971 to 2007 followed by Russia (-5.47 %) and Brazil (-0.28 %). $CO_2$ emission intensity of Indonesia is increasing at a rate of 1.14% followed by South Africa (0.28 %) and India (0.11%)(Table 4).




2. **Pattern of** $CO_2$**Emission Intensity in Developed Countries**

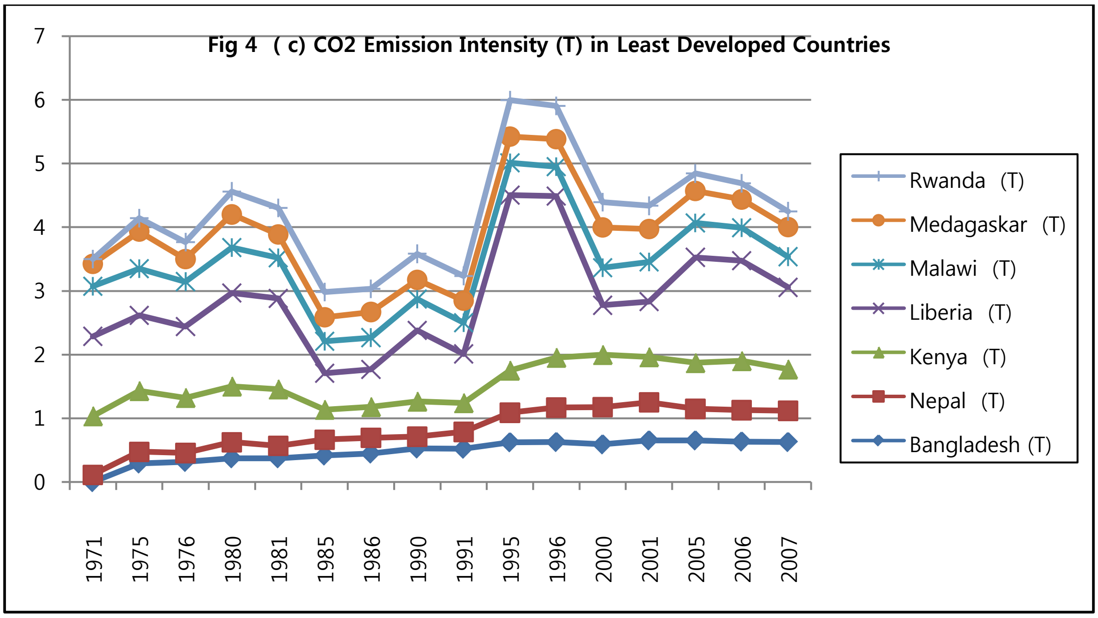
Canada has the highest emission intensity since 1970s. However, all the developed countries have shown similar pattern of reduction (Fig 4(b). With regard to average annual growth rate all developed countries have negative growth rate of

$CO_2$emission intensity. Lowest $CO_2$ emission intensity is of Germany (-3.18%) followed by UK (-2.91%), France(-2.89%), USA (-1.58%), Japan (-1.14%), Italy (-1.05%) and then Canada (-0.99%) (Table4). It shows the production technologies of Germany and more environmental friendly and that of Canada the least.




3. **Pattern of $CO_2$ Emission Intensity in Least Developed Economies**

Among LDCs, Bangladesh has lowest $CO_2$ emission intensity followed by Nepal and Kenya. Rwanda, Madagascar, Malawi and Liberia follow the same pattern in case of $CO_2$ emission intensity (Fig 4 (c)).With regard to average annual growth rate Liberia has the maximum 6.09% followed by Rwanda (5.20%), Nepal (5.13%), Madagascar (4.39%), Bangladesh (1.56%), Malawi(-1.09%) and then Kenya (-1.35%). Only two counties viz. Malawi and Kenya have shown negative trends. However, in case of Kenya barring negative growth during 1981-85 and 2006-2007 the trends have been positive sine 1971 to 2007. Contrary to that in case of Malawi, $CO_2$ emission intensity was positive only between 1976-80 and then from 1991to 2000. It shows that Malawi has tried to amply clean technologies.




C. **Results of IPAT model - Hypothesis Testing**

In the preceding paragraphs the magnitude of three variables from the year 1971 to 2007 is presented. In addition, their growth rates during this period have also been discussed. Now these variables are subjected to analysis in the in IPAT model. At the same time our hypothesis will also be tested as to which of the variables is causing more harm in terms of release of $CO_2$ as a pollutant. It is discussed as under:

A. **Total Impact (I') and relative percentage of three variables, P' A' and T'**

**i) Case of Developing Countries**

As is evidentfrom the Table 5, total impact 'I' is very high in developing countries. The units of pollution range from 4.47 in case of South Africa to 7.93 in case of Indonesia. Only Russia has shown negative impact in terms of pollution caused by $CO_2$ emission. In all countries, exceptRussia, the percent contribution of Affluence (GDP per capita) is highest than other two variables. It is also clear from Fig4 (a)(i) and Fig 4(b)(i).

It is also evident from the Table 5 that percent contribution of GDP per capita i.e. affluence factor (A) in case of Brazil is 75.84%; India is 75.38%, China 120.88%;

South Africa 55.56 %; Indonesia 66.97%; and Malaysia 78.25 % which is the highest contribution among all three factors. In case of Russia, total impact 'I' is negative (-0.21). Though the CO2 emission intensity of China (-2.62) and Malaysia (-0.36) are negative, yet they are not making much influent to bring total impact below zero.

**Fig. 4 (a) (i) : I', P', A' and T' in Developing Economies from 1971 to 2007**

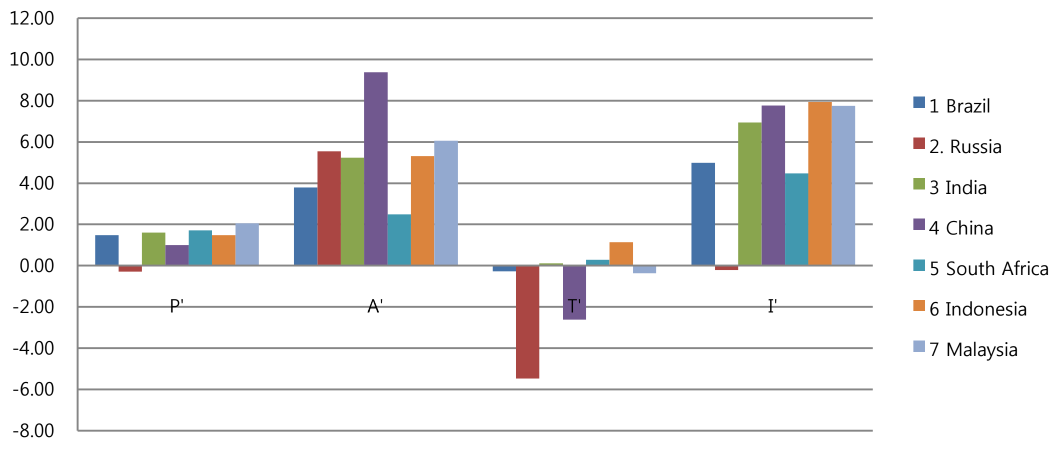
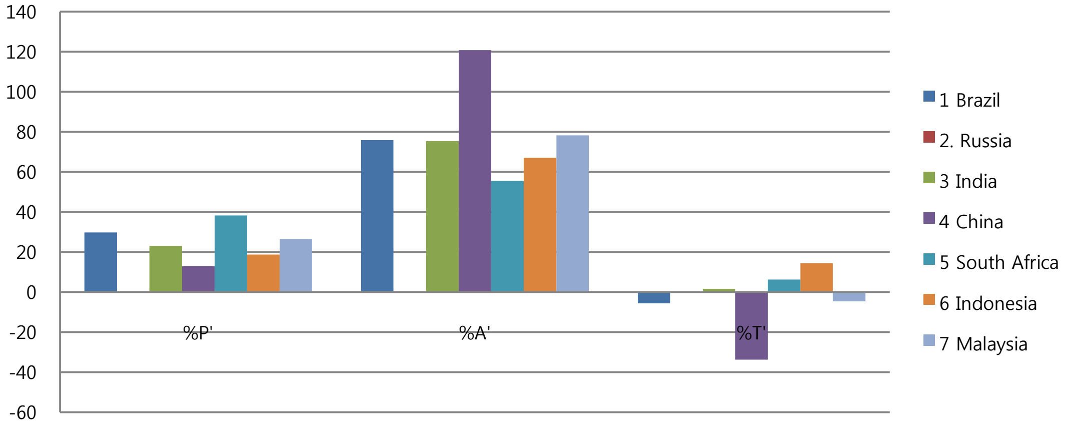



**Fig. 4 (b) (i). Percentage of P' A' and T' in Impact (I') in Developing Ecnonomies.**



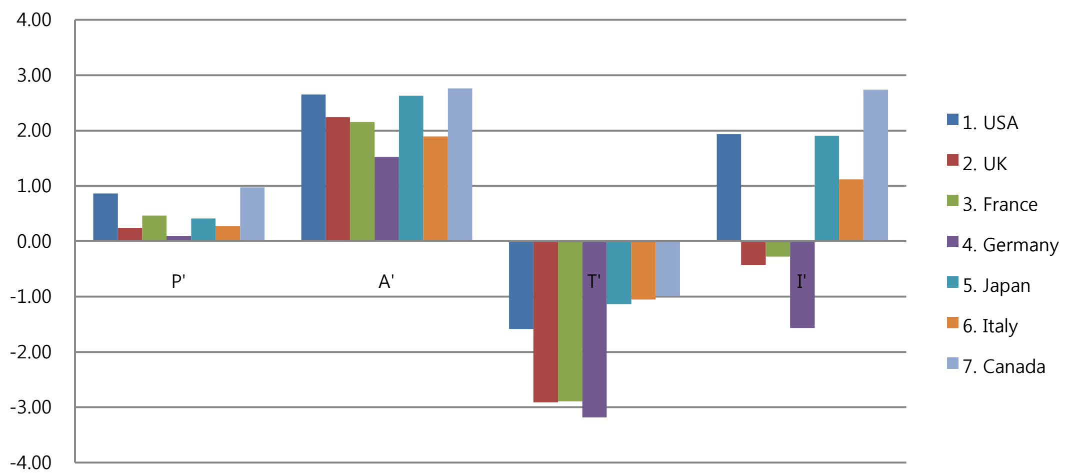

## ii) Case of Developed Countries

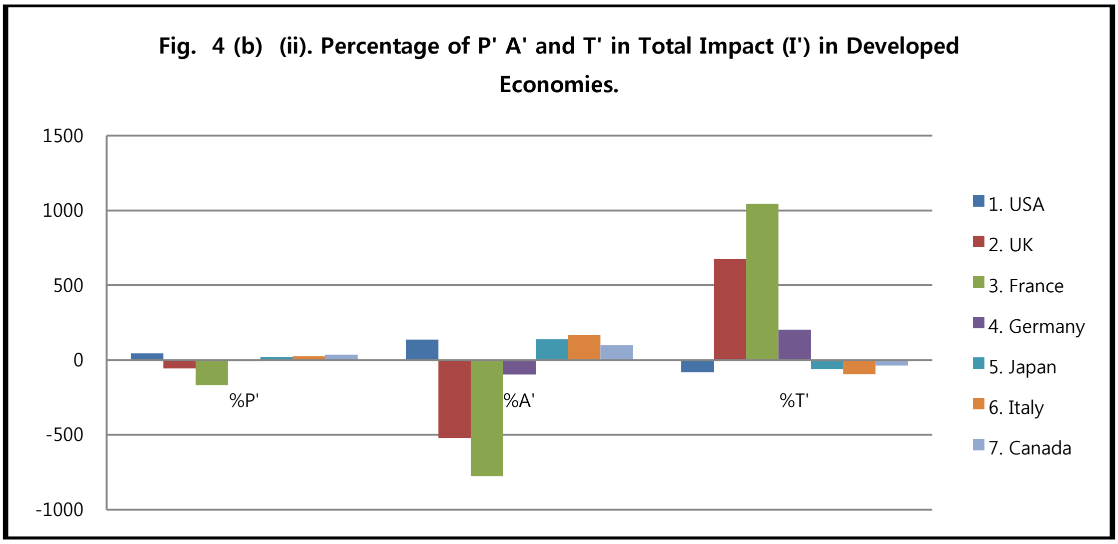
In case of developed countries, Germany, UK and France don't contribute to any impact on pollution. Their impact is -1.56, -0.43 and -0.27 respectively. However, the economies of Canada, USA, Japan and Italy cause damage to the environment as their total impact is 2.73, 1.93, 1.90 and 1.10 respectively (Table 5). It shows that though $CO_2$ intensity is -1.58 for USA; -1.14 for Japan; -1.05 for Italy; and -0.99 for Canada yet, their technologies are not taking care of huge impact being posed by economic development.

With regard to the relative percentage of variables in the total Impact, it is Affluence (GDP per capita) which is causing maximum damage. 'A' factor is 137.22% for USA; 138.21% for Japan; 169.63% for Italy and 100.77% in case of Canada showing that economic development is causing more damage than both the other factors. The case of Germany, France and UK is not considered because their economies are not damaging the environment.(Fig 4 (a) (ii); and Fig (b) (ii).

The technological factor (T') of UK (-2.9); France (-2.89); and Germany (-3.18) is taking care of the harmful impact of population growth and economic development. The bad impact posed by these two factors is counter balanced by technology so that there is no bad impact on environment.

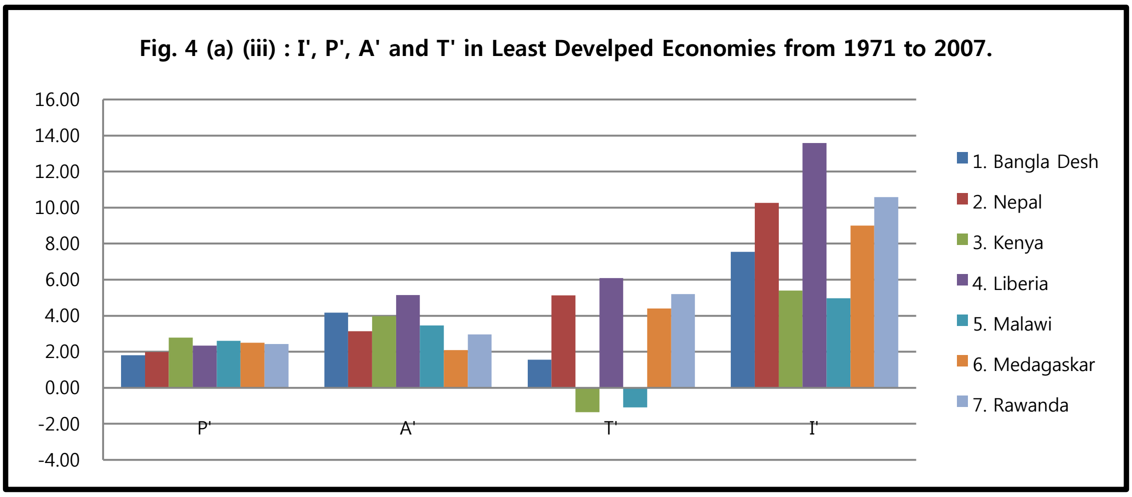
Fig. 4 (a) (ii) : I', P', A' and T' in Developed Economies from 1971 to 2007

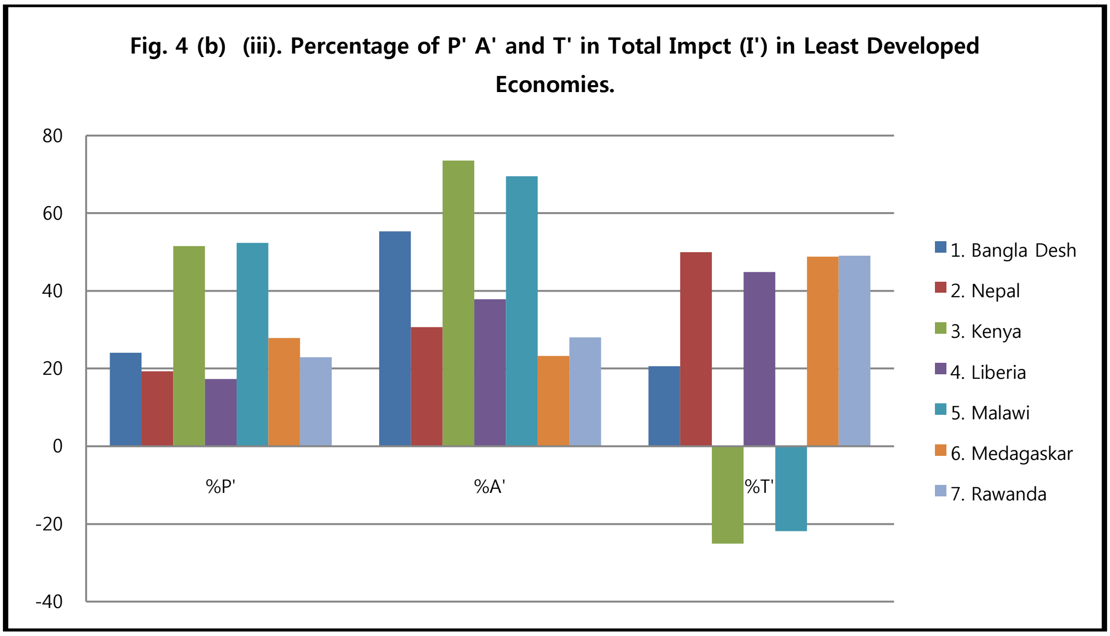





### iii) Case of Least Developed Economies

Among Least Developed Economies, Liberia, Rwanda and Nepal are causing maximum damage to the tune of 13.59, 10.59 and 10.25 unitsrespectively (Table 5). It is followed by Madagascar (8.99). The pattern of Bangladesh, Kenya & Malawi is like developing economies. It is interesting to note that in countries viz. Nepal, Liberia, Madagascar and Rwanda the maximum damage is caused by technology (T') factor which is 50.02% in case of Nepal; 44.83% in case of Liberia; 48.83% in case of Madagascar; and 49.08% in case of Rwanda. It appears that the technologies of these countries are not environmental friendly. Fig4 (a)(iii) and Fig4(b)(iii).






**B Test of Hypothesis**

From the Table5, it appears that the affluence (A') i.e. GDP growth (per capita) is causing maximum damage to the tune of 137.22% for USA; 138.21% for Japan; 169.63% for Italy and 100.77% in case of Canada. In case of Brazil it is 75.84%; India is 75.38%, China 120.88%; South Africa 55.56 %; Indonesia 66.97%; and Malaysia 78.25 %.

However, in case of least developed economies the technological factor (T') is causing maximum damage which is 50.02% in case of Nepal; 44.83% in case of Liberia; 48.83% in case of Madagascar; and 49.08% in case of Rwanda.

Hence, it is proved that in case of developed and developing economies it is the economic growth which causes more damage to the environment than population growth and technological developments. However, in case of poor economies this is technological factor which causes more damage to the environment.

**Table 5: Total Impact (I’) with relative %ge of three variables viz. Population(P’), Affluence(A’) and Technology (T’) from the year 1971 to 2007.**

| | P’ (% P’) | A’ (%A’) | T’ (%T’) | Co2 | I’ |
|---|---|---|---|---|---|
| **Developing Economies** | | | | | |
| 1 Brazil | 1.48 (29.71%) | 3.79 (75.84%) | -0.28 (-5.55%) | 3.47 | 4.99 |
| 2. Russia | -0.29 (133.73%) | 5.55 (-2591.13%) | -5.47 (2,557.40%) | -0.67 | -0.21 |
| 3 India | 1.60 (23.03%) | 5.23 (75.38%) | 0.11 (1.59%) | 5.33 | 6.94 |
| 4 China | 1.00 (12.91%) | 9.38 (120.88%) | -2.62 (-33.79%) | 5.76 | 7.75 |
| 5 South Africa | 1.71 (38.21%) | 2.49 (55.56%) | 0.28 (6.23%) | 2.73 | 4.47 |
| 6 Indonesia | 1.48 (18.68%) | 5.31 (66.97%) | 1.14 (14.35%) | 6.50 | 7.93 |
| 7 Malaysia | 2.05 (26.46%) | 6.06 (78.25%) | -0.36 (-4.71%) | 5.73 | 7.74 |
| | | | | | |
| **Developed Economies** | | | | | |
| 1. USA | 0.86 (44.72%) | 2.65 (137.22%) | -1.58 (-81.95%) | 0.86 | 1.93 |
| 2. UK | 0.24 (-55.11%) | 2.24 (-520.70%) | -2.91 (675.81%) | -0.94 | -0.43 |
| 3. France | 0.47 (-167.98%) | 2.15 (-776.25%) | -2.89 (1044.23%) | -1.01 | -0.27 |
| 4. Germany | 0.09 (-6.05%) | 1.52 (-97.24%) | -3.18 (203.29%) | -1.82 | -1.56 |
| 5. Japan | 0.41 (21.61%) | 2.63 (138.21%) | -1.14 (-59.82%) | 1.31 | 1.90 |
| 6. Italy | 0.28 (24.73%) | 1.89 (169.63%) | -1.05 (- 94.36%) | 0.76 | 1.11 |
| 7. Canada | 0.97 (35.50%) | 2.76 (100.77%0 | -0.99 (-36.28%) | 1.64 | 2.73 |
| | | | | | |
| **Least Developed Economies** | | | | | |
| 1. Bangla Desh | 1.81 (24.05%) | 4.17 (55.31%) | 1.56 (20.65%) | 6.00 | 7.54 |
| 2. Nepal | 1.98 (19.29%) | 3.15 (30.69%) | 5.13 (50.02%) | 8.96 | 10.25 |
| 3. Kenya | 2.78 (51.51%) | 3.97 (73.54%) | -1.35 (-25.06%) | 2.58 | 5.39 |
| 4. Liberia | 2.35 (17.28%) | 5.15 (37.89%) | 6.09 (44.83%) | -0.61 | 13.59 |
| 5. Malawi | 2.60 (52.35%) | 3.46 (69.53%) | -1.09 (-21.87%) | 2.23 | 4.96 |
| 6. Medagaskar | 2.51 (27.89%) | 2.09 (23.28%) | 4.39 (48.83%) | 6.79 | 8.99 |
| 7. Rawanda | 2.43 (22.90%) | 2.97 (28.02%) | 5.20 (49.08%) | 7.71 | 10.59 |

**C.Path followed by individual countries in IPAT model**

The relations of IPAT parameters are examined in case of all 21 economies. Following two types of patterns are observed:

**a) Case 1 where total Impact (I') travels above all other factors:**

This relations is observed in developing and least developed economies viz. Brazil(Fig 4(i)), South Africa (Fig 4(v)), Indonesia (Fig 4(vi)), Malaysia (Fig 4(vii)), Bangladesh (Fig4(xv)), Nepal(Fig4 (xvi)), Kenya(Fig4(xvii)), Malawi(Fig4(xix)) and Madagascar (Fig4(xx)). In case of India I' is above all other factors till the year 2000. After that GDP per capita (A') came above all (Fig 4(iii)).

These are the most polluting economies.

**Fig. 4(i): I' P' A' and T' in case of Brazil.**

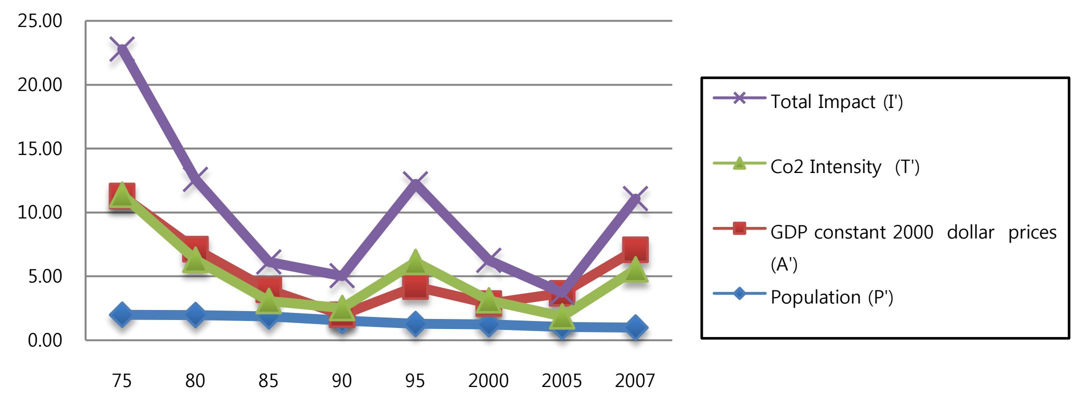



**Fig 4 (v): I' P' A' and T' in case of South Africa.**

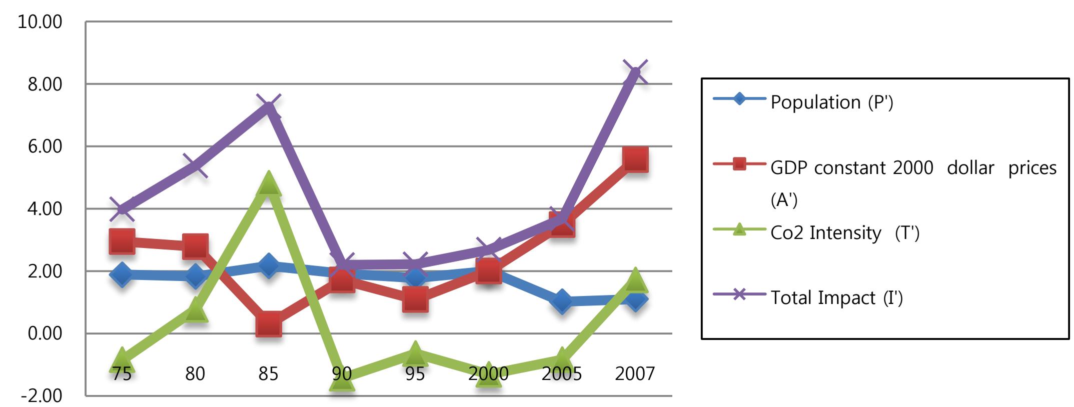


**Fig. 4 (xvi): I' P' A' and T' in case of Nepal.**

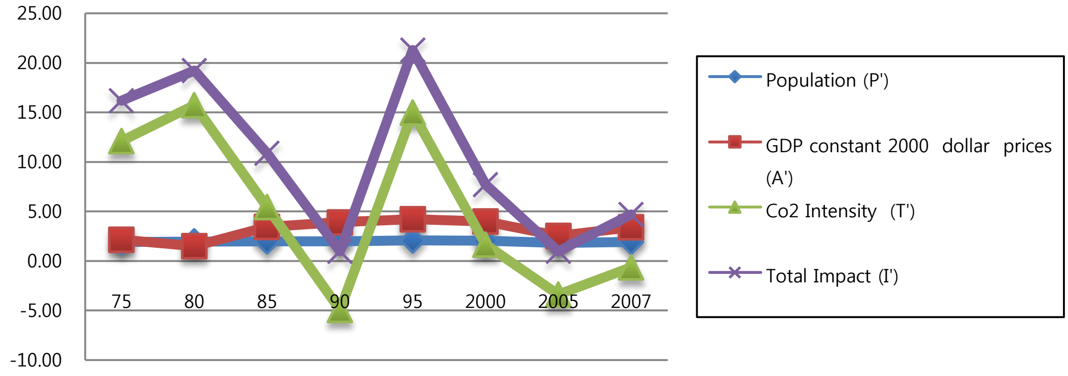



**Fig. 4(xv): I' P' A' and T' in case of Bangladesh.**

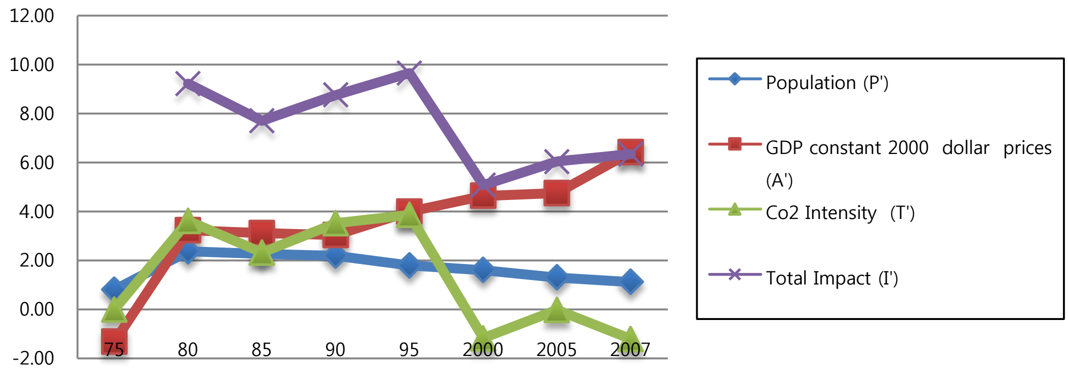
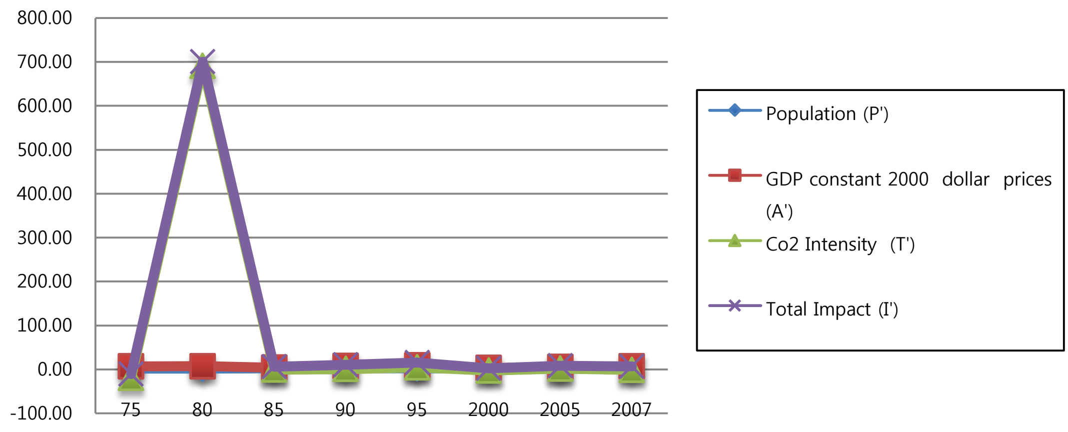



**Fig 4 (vii): I' P' A' and T' in case of Malaysia.**



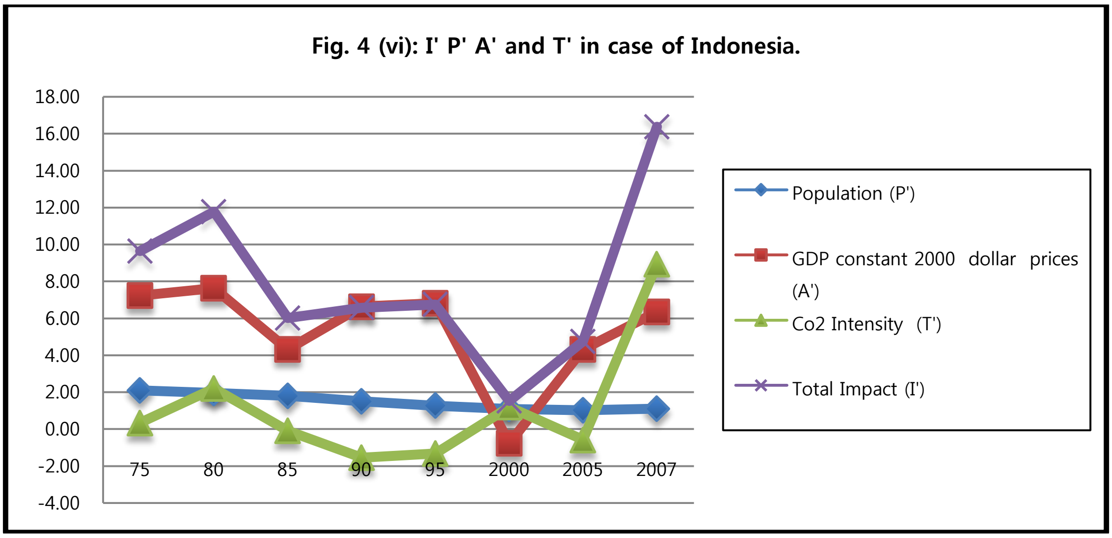


Fig. 4 (vi): I' P' A' and T' in case of Indonesia.

**ii) Case 2 where Affluence (A') travelled above all other factors**

This pattern is found in UK (Fig 4(ix)), France (Fig4(x)), Germany (Fig 4(xi)), and Russia (Fig 4(ii)). These economies have been found clean economies because total impact is below population pressure and economic development. The technologies are so advanced that they are counterbalancing the harmful impact of population growth and economic development.

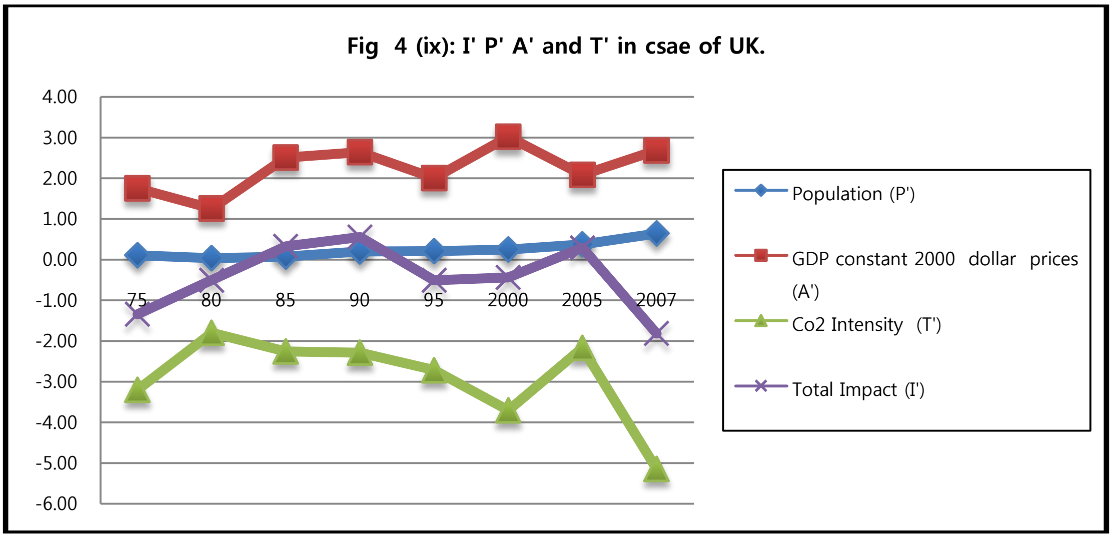


Fig 4 (ix): I' P' A' and T' in csae of UK.

Fig 4 (x): I' P' A' and T' in case of France.

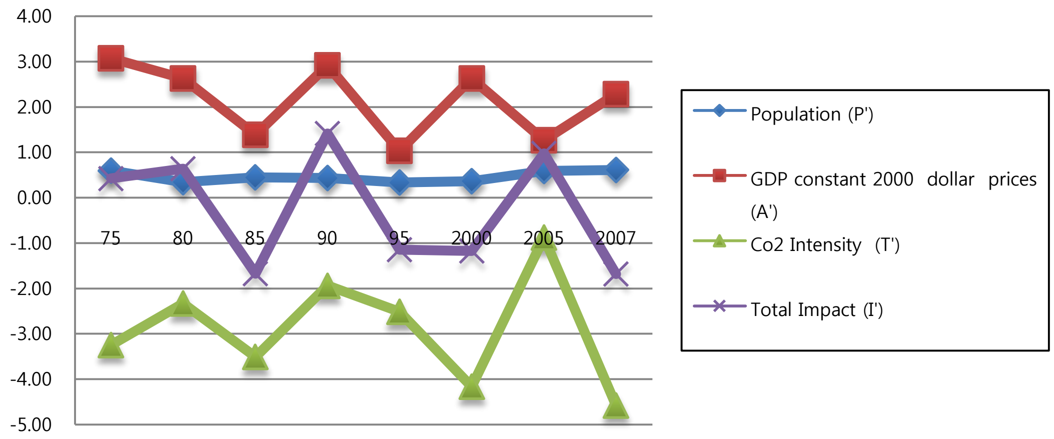



Fig. 4 (xi): I' P' A' and T' in case of Germany.

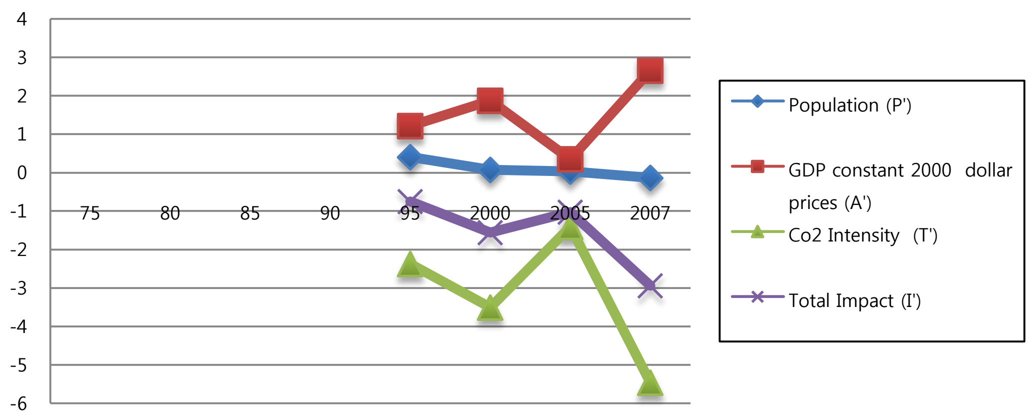
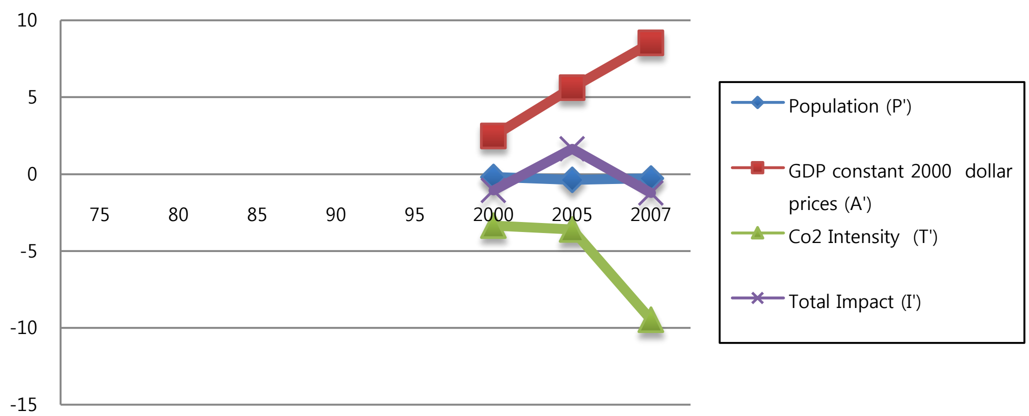



Fig. 4 (ii): I' P' A' and T' in case of Russia.



### iii) Case 3 where Impact (I') travels between Affluence (A') and Population (P')

In countries, USA, Japan, Italy, Canada, India and China, Impact (I') is between A' and P'

**Fig. 4 (viii): I' P' A' and T' in case of USA.**

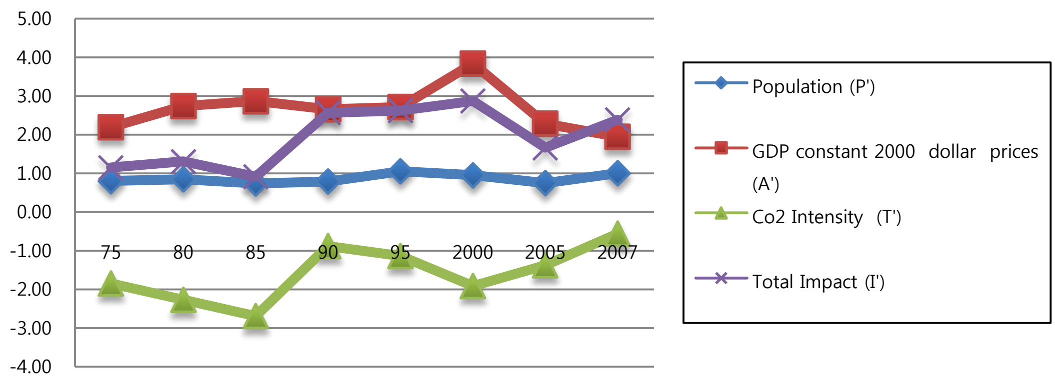



**Fig. 4 (xii: I' P' A' and T' in case of Japan.**

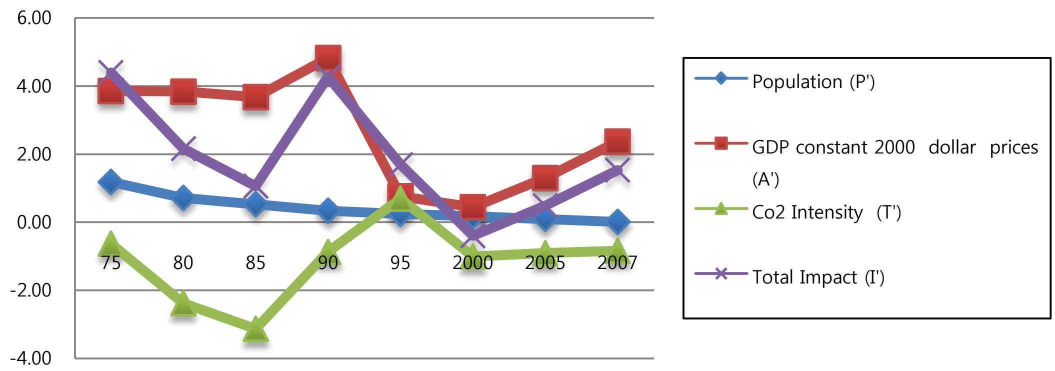
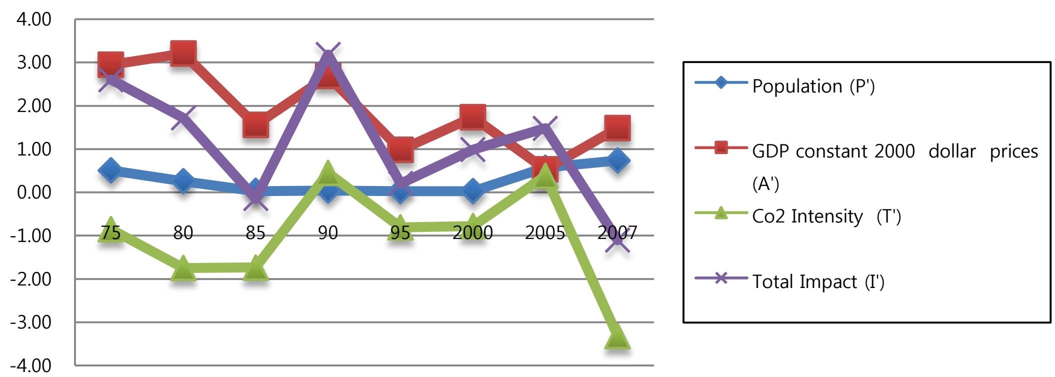



**Fig. 4 (xiii): I' P' A' and T' in case of Italy.**



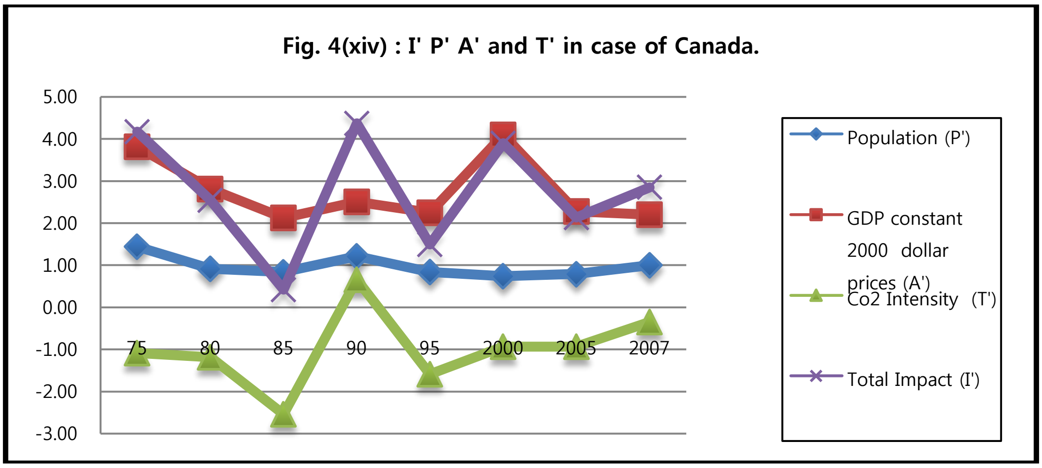


Fig. 4(xiv) : I' P' A' and T' in case of Canada.
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
75
80
85
90
95
2000
2005
2007
Population (P')
GDP constant 2000 dollar prices (A')
Co2 Intensity (T')
Total Impact (I')

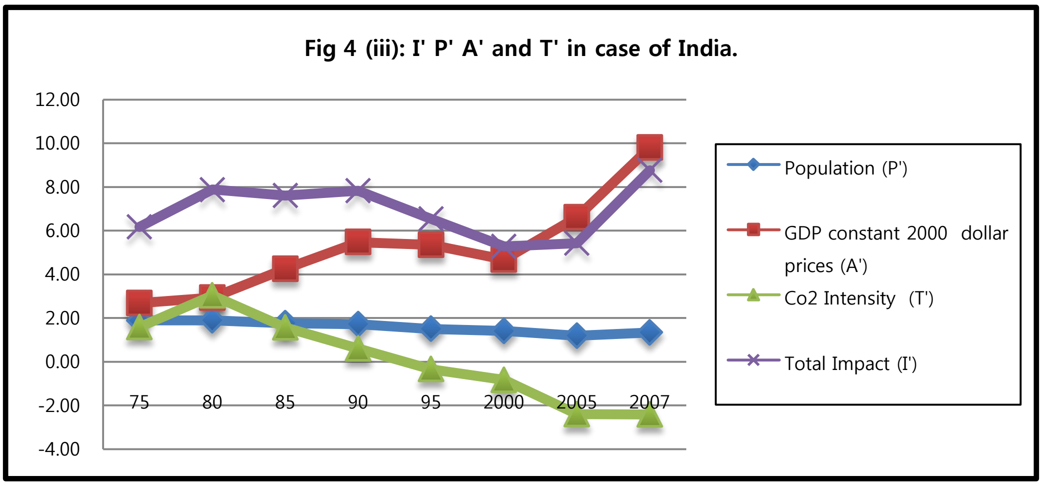


Fig 4 (iii): I' P' A' and T' in case of India.
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
75
80
85
90
95
2000
2005
2007
Population (P')
GDP constant 2000 dollar prices (A')
Co2 Intensity (T')
Total Impact (I')

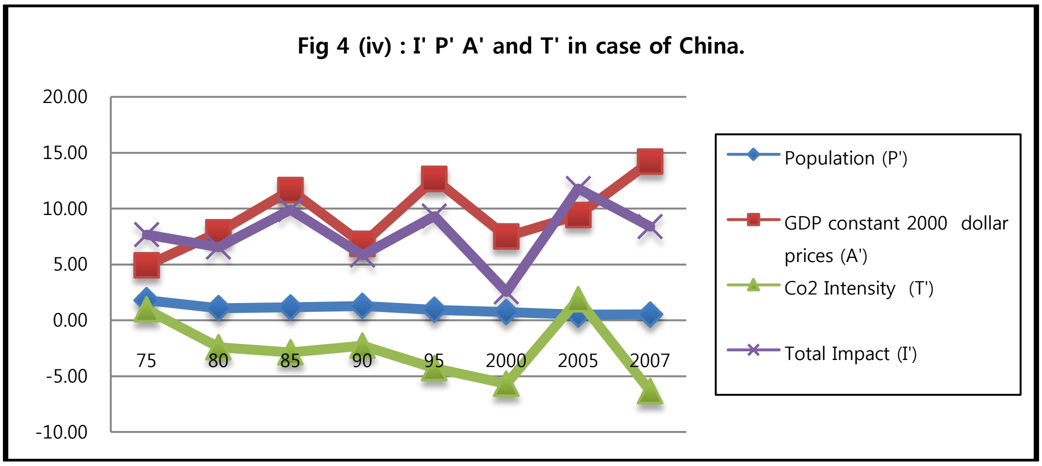
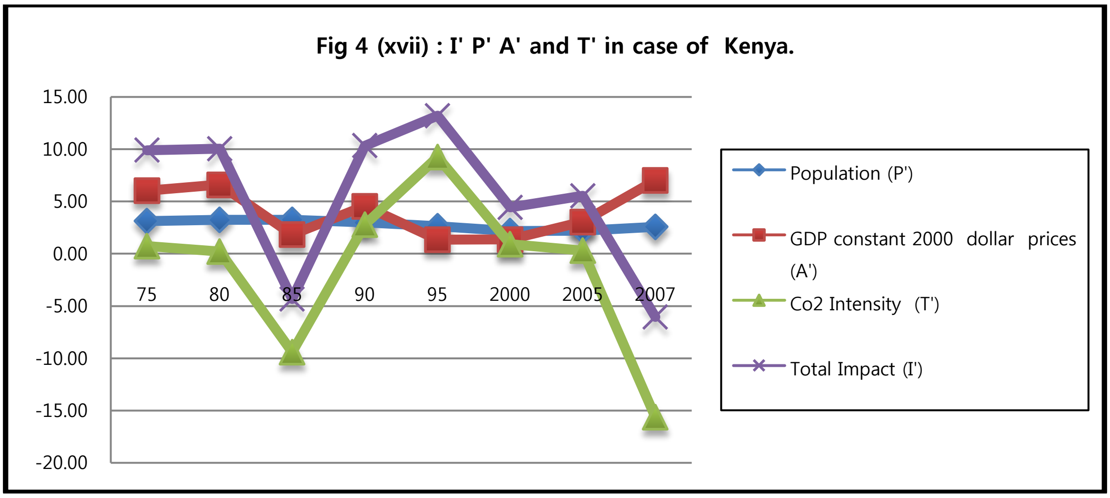


Fig 4 (iv) : I' P' A' and T' in case of China.
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
75
80
85
90
95
2000
2005
2007
Population (P')
GDP constant 2000 dollar prices (A')
Co2 Intensity (T')
Total Impact (I')

**iv) Case 4 where movement of all the three factors is not defined**

In Least Developed Economies viz. Kenya (Fig 4(xvii)), Liberia (Fig4(xviii)), Malawi(Fig(4(xix)) and Rwanda (Fig4(xix)) the movement of all the factors is not defined. At one point of time one factors moves at the top at another time other factors play important role in total impact. It is evident from the following figures.



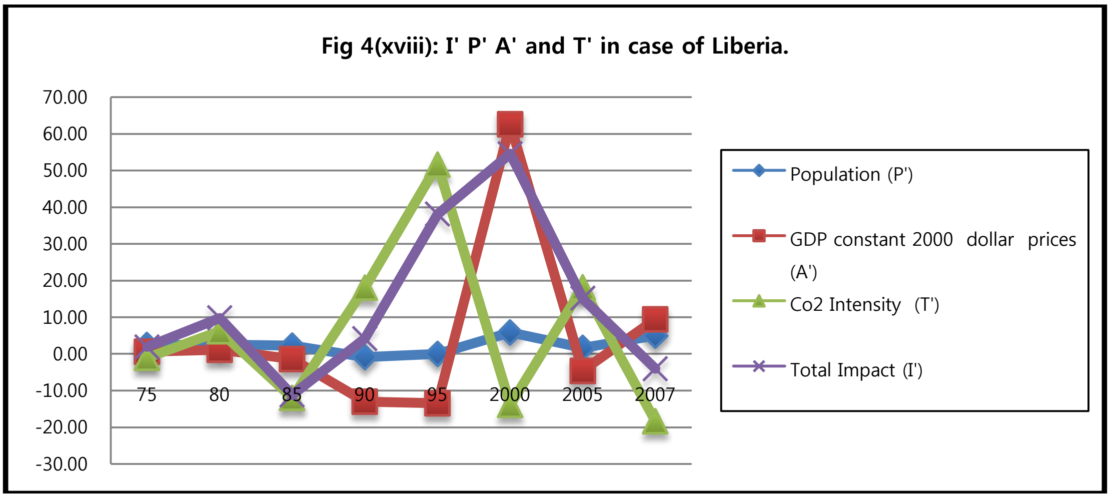



Fig 4 (xix): I' P' A' and T' in case of Malawi.

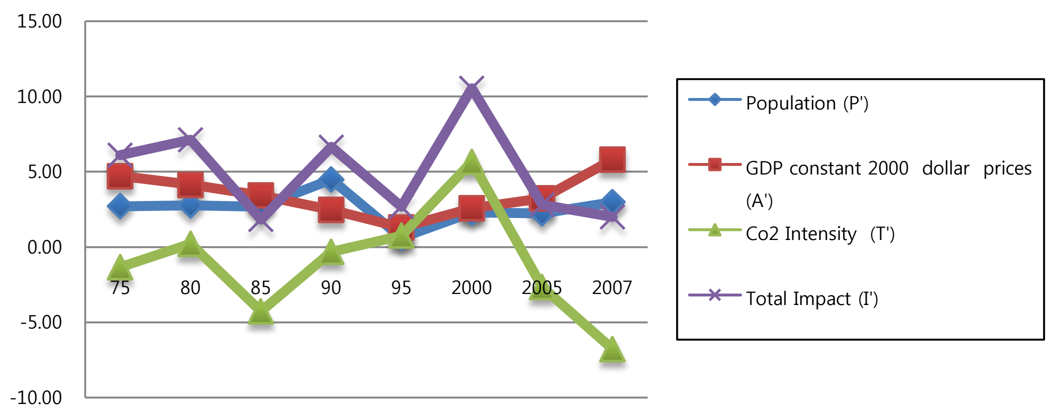



Fig 4 (xx): I' P' A' and T' in case of Madagasker.

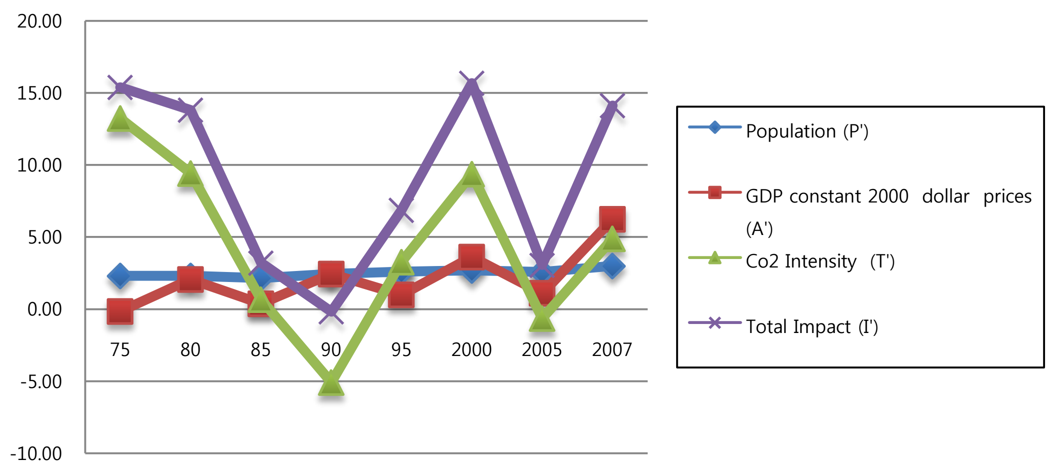
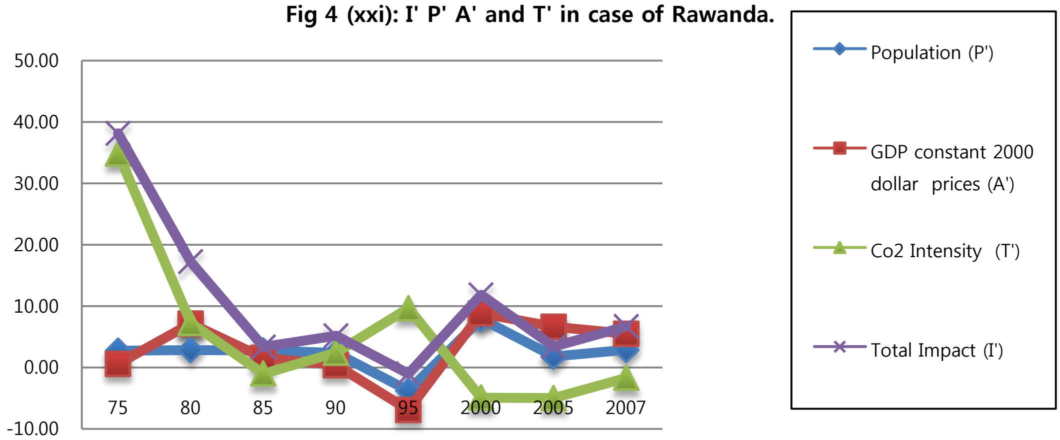



Fig 4 (xxi): I' P' A' and T' in case of Rawanda.



D. **Relation between $CO_2$ emission and Economic Development in Environmental- Kuznets-Curve**

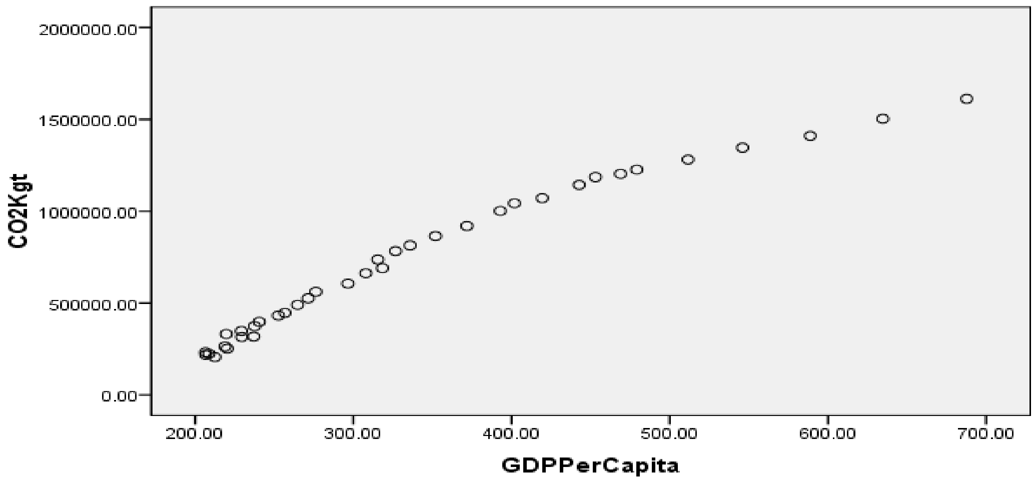
In the preceding section it has been found that the most detrimental factor for the release of $CO_2$ is GDP per capita However, what pattern does $CO_2$ emission follow along the developmental path of a country is examined in his section. All 21 countries of three categories of economies are subjected to analysis in Environmental-Kuznets-Curve by plotting total $CO_2$ emission against GDP per capita.

Following 4 types of relations are found:

**Relation 1: Smooth upward movement – positive relation between $CO_2$ Emission and economic growth (GDP per capita)**

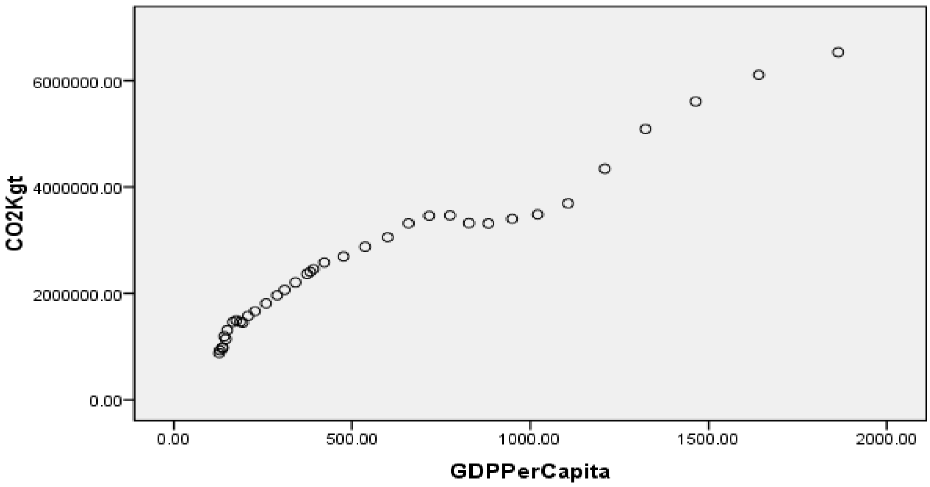
It is found that India, China, Indonesia, Malaysia, Bangladesh, Nepal and Brazil follow continuous upward movement of $CO_2$ release along the path of development. It is evident from the following Fig (3, 4, 6, 7, 8, 9 and 1). It is scale effect of the economy. As the economy grows the $CO_2$ emission increases.

**Fig. 3: CO2 Emission versus GDP Per Capita in India**



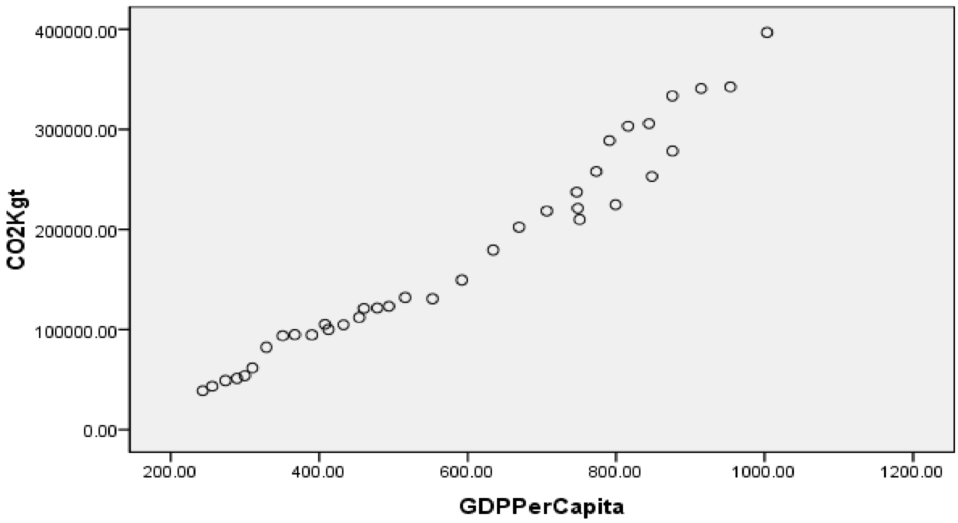

Note: GDP Per Capita at year 2000 $ prices; CO2 emitted in Kgt.

Fig 4: CO2 Emission (Kgt) versus GDP Per Capita in China



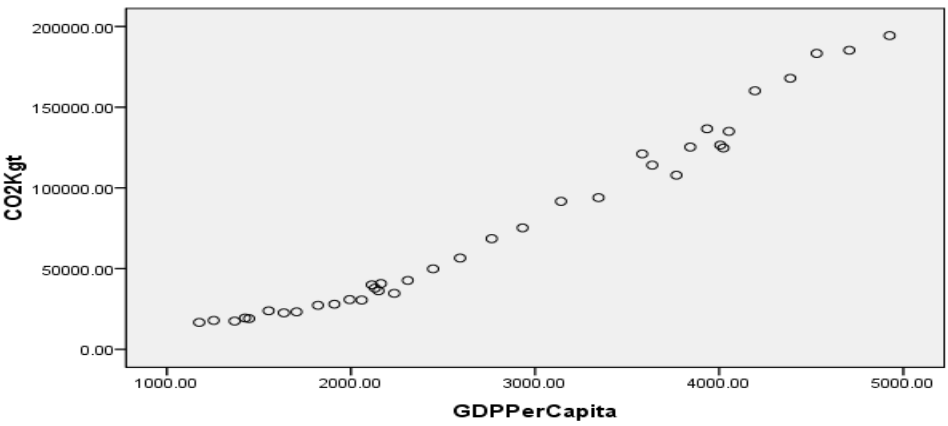

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

Fig 6: CO2 Emission (Kgt) versus GDP Per Capita in Indonesia



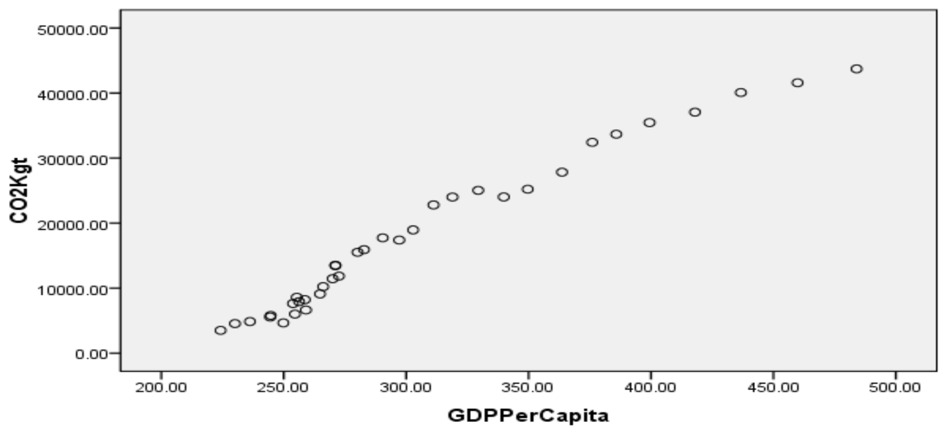

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

Fig 7: CO2 Emission (Kgt) versus GDP Per Capita in Malaysia



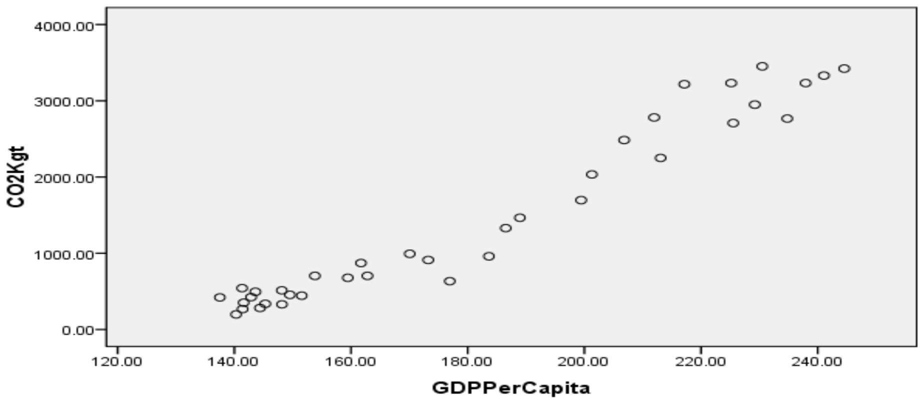

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

Fig 8: CO2 Emission (Kgt) versus GDP Per Capita in Bangla Desh



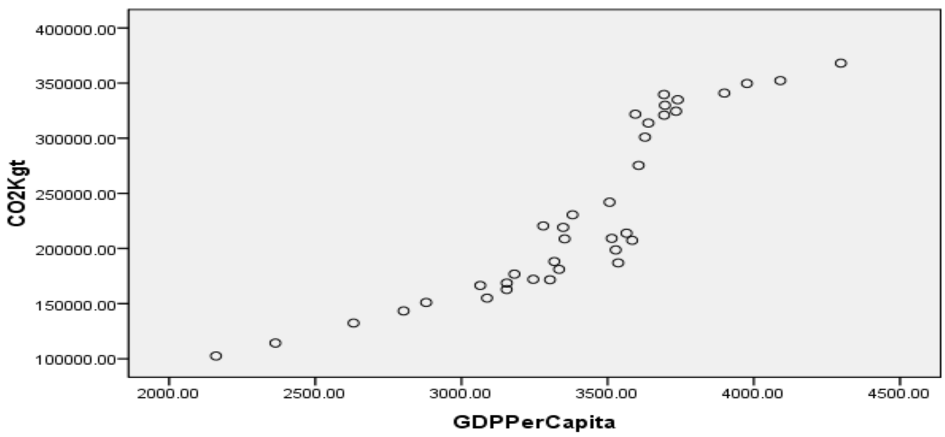

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Fig 9: CO2 Emission (Kgt) versus GDP Per Capita in Nepal**



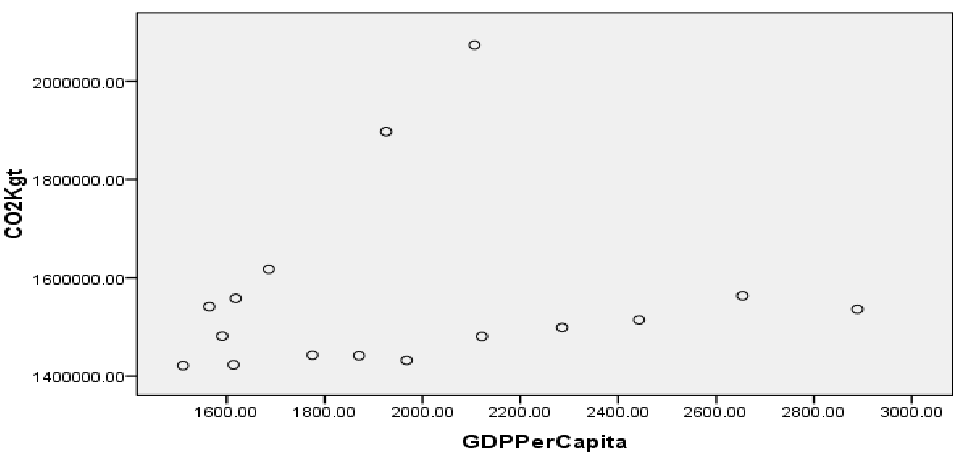

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Fig 1: CO2 Emission versus Per Capita GDP of Brazil**




Note: GDP per capita at year 2000AD $ prices; CO2 (Kgt) emitted

**Fig 2: CO2 Emission (Kgt) versus GDP per capita in Russia**

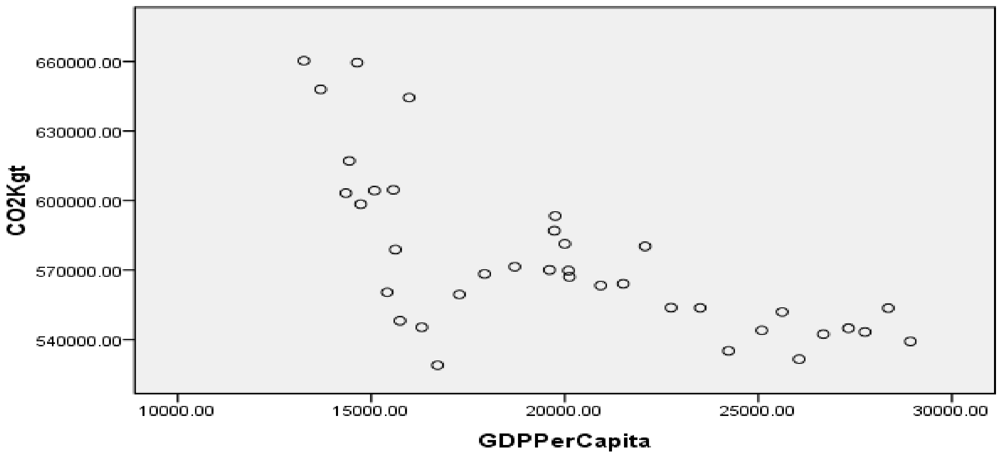



Note : GPD per capita at year 2000 $ prices; CO2 (Kgt)

**Relation 2: Downward movement of the curve (negative relation between $CO_2$ Emission and GDP per capita)**

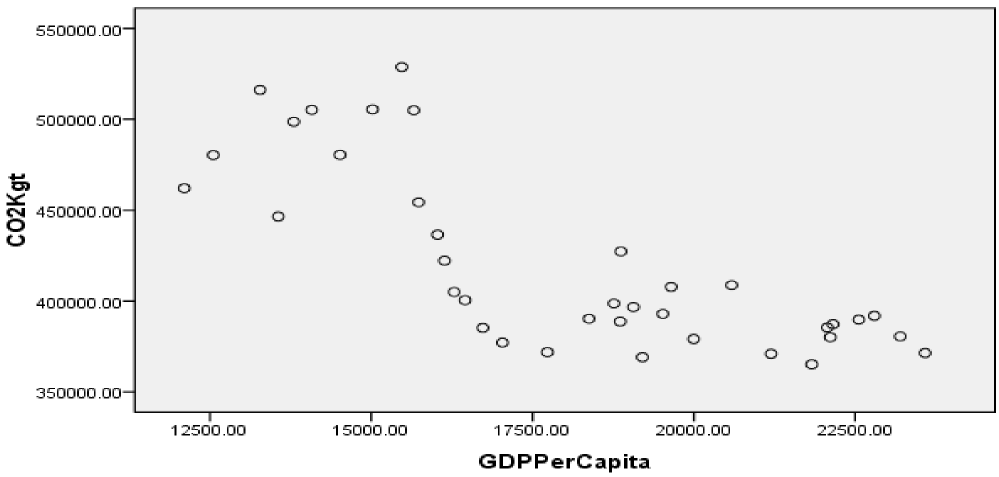
The countries, UK, France and Germany are following a definite negative relation between $CO_2$ emission and GDP per capita as is evident from the Figs 16, 17 & 18. This is technological affect. As the policies of country are environmental friendly the $CO_2$ emission is contained.

Fig 16: CO2 Emission (Kgt) versus GDP Per Capita in UK



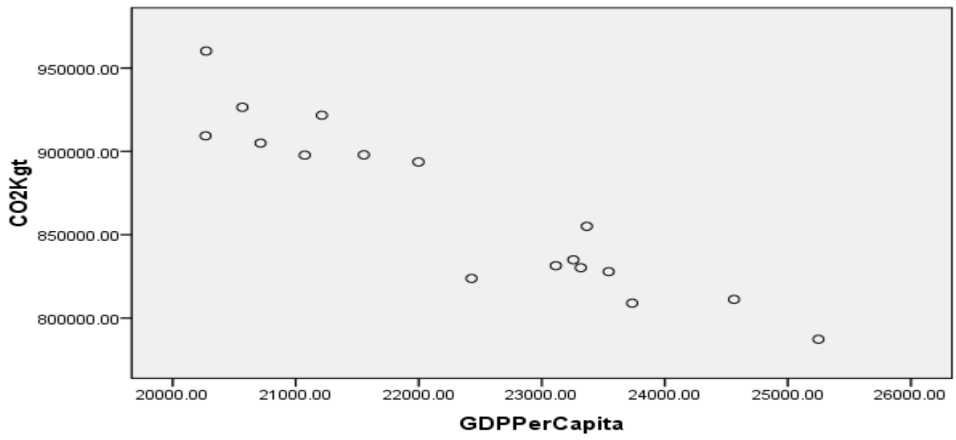

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

Fig 17: CO2 Emission (Kgt) versus GDP Per Capita in France




Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Fig 18: CO2 Emission (Kgt) versus GDP Per Capita in Germany**

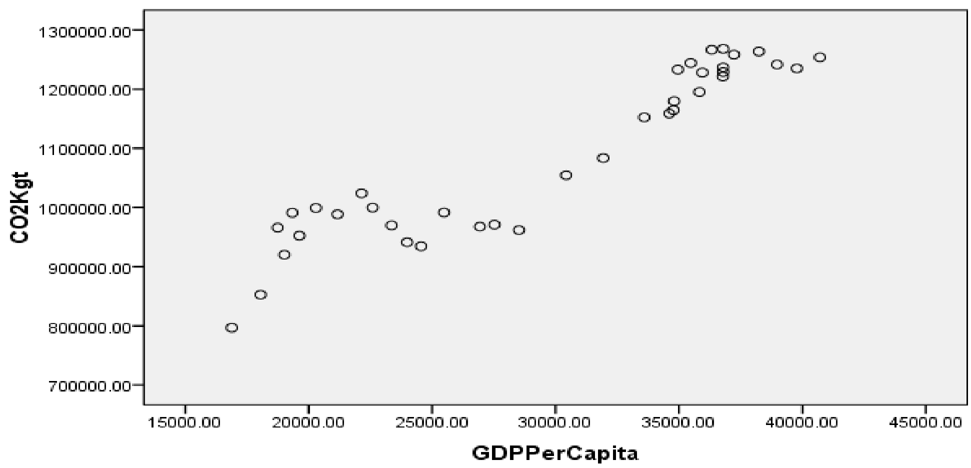



Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Relation 3: 'N' shaped relation between $CO_2$emissions and GDP percapita.**

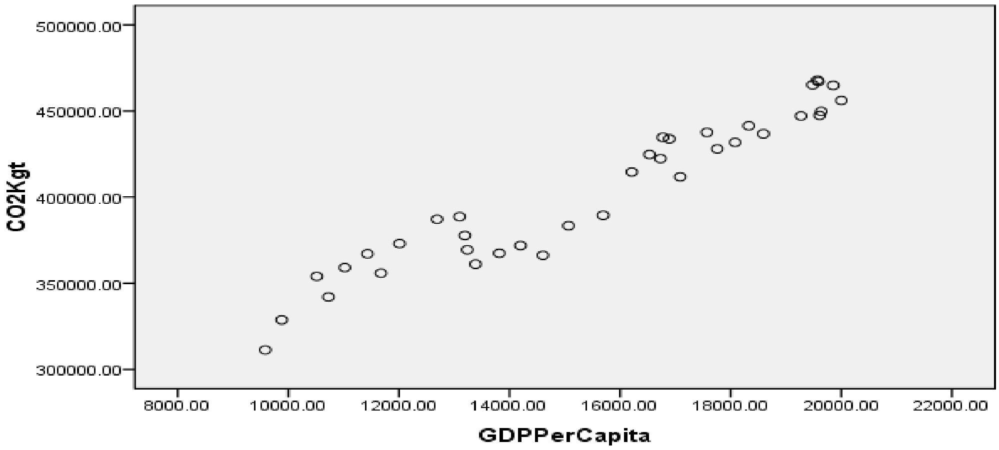
In countries Japan, Italy, USA and Canada 'N' type of relation has been observed in emission of $CO_2$ and GDP per capita. It is clear from Fig 15, 19, 20 and 21.

**Fig 19: CO2 Emission (Kgt) versus GDP Per Capita in Japan**



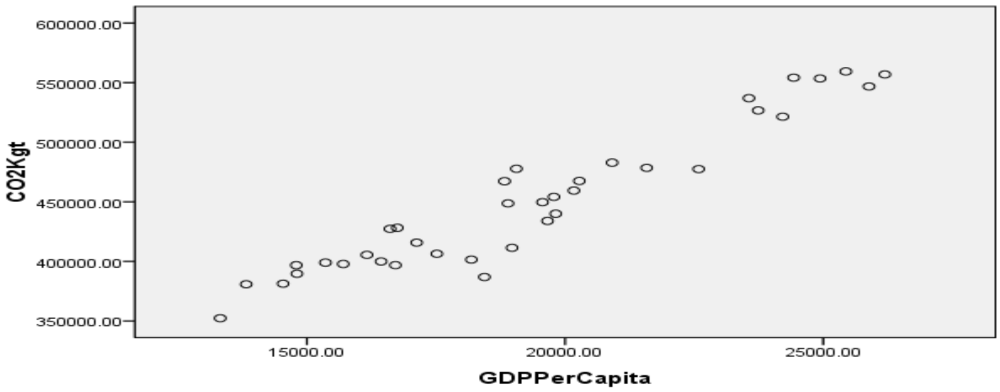

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Fig 20: CO2 Emission (Kgt) versus GDP Per Capita in Italy**



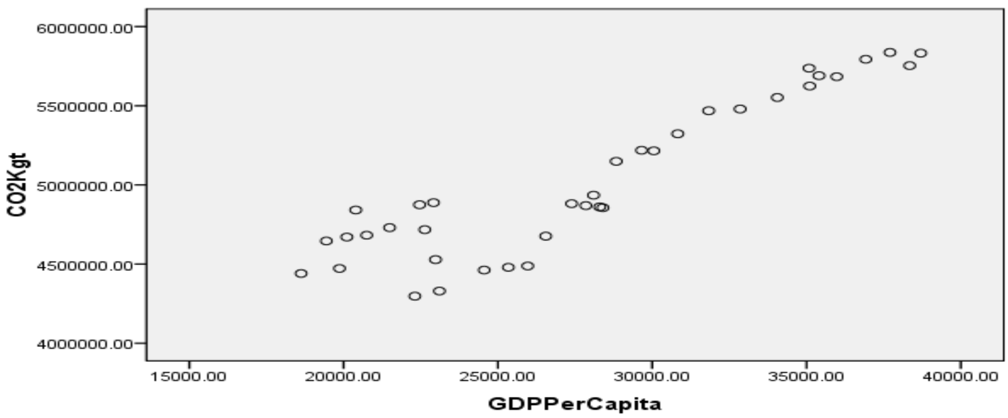

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Fig 21: CO2 Emission (Kgt) versus GDP Per Capita in Canada**




Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Fig 15: CO2 Emission (Kgt) versus GDP Per Capita in USA**

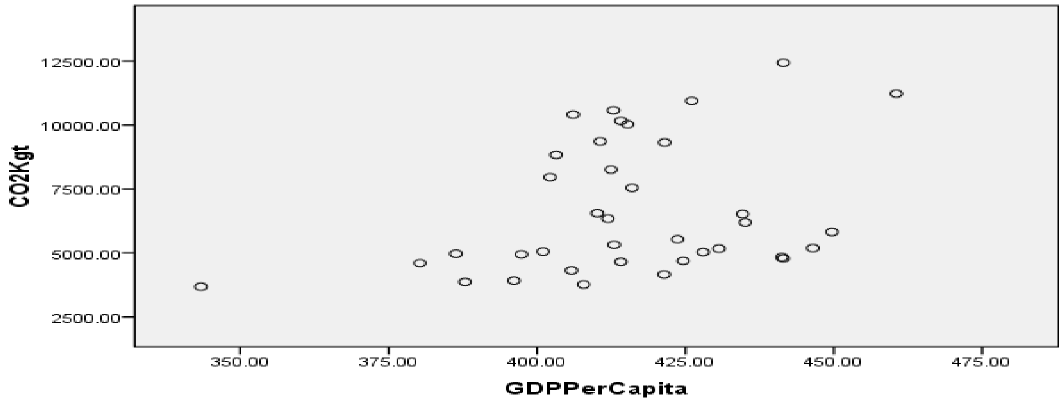



Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Relation 4:No relation between $CO_2$ emission and GDP per capita**

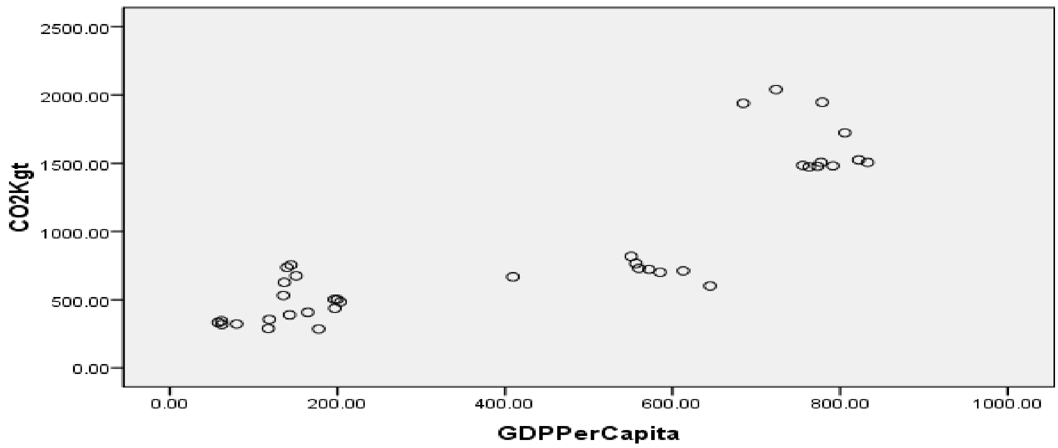
In poorest countries like Kenya, Liberia, Malawi, Madagascarand Rwanda no relation has been found. Even this type of movement is found in South Africa. It is clear from the Fig 10, 11, 12, 13, 14 and 5.

**Fig 10: CO2 Emission (Kgt) versus GDP Per Capita in Kenya**



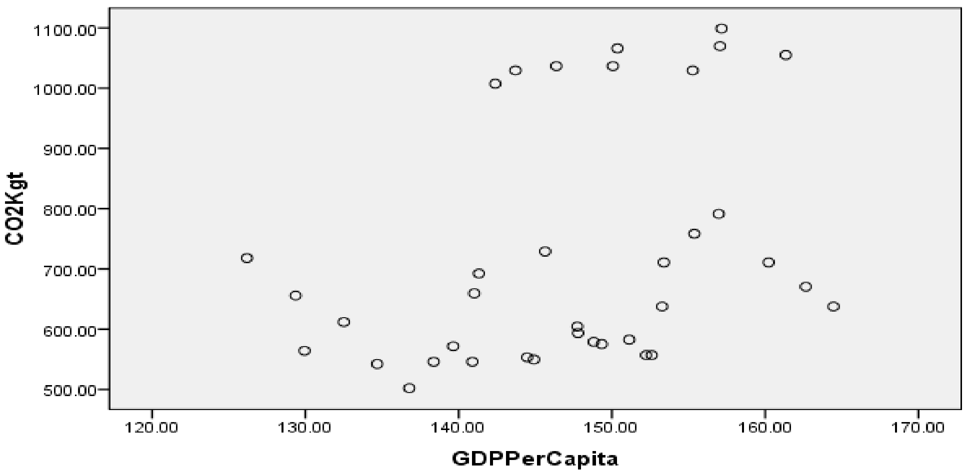

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

**Fig 11: CO2 Emission (Kgt) versus GDP Per Capita in Liberia**



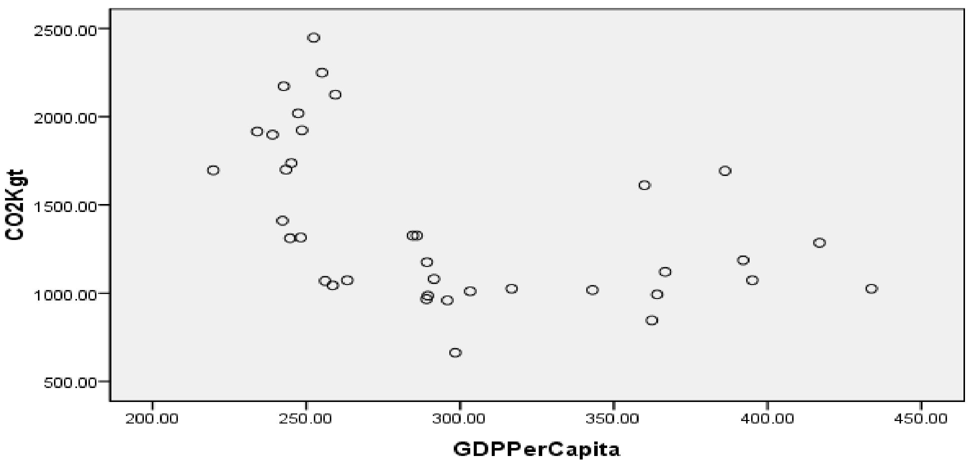

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

Fig 12: CO2 Emission (Kgt) versus GDP Per Capita in Malawi



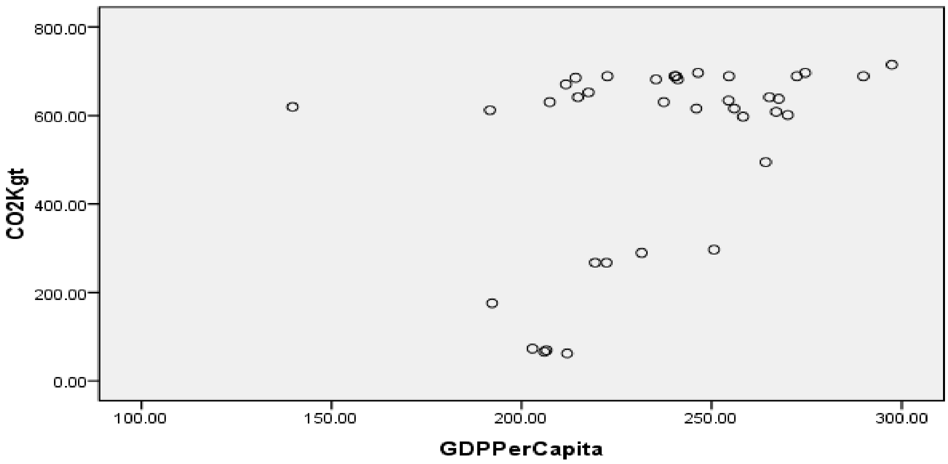

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

Fig 13: CO2 Emission (Kgt) versus GDP Per Capita in Madagasker



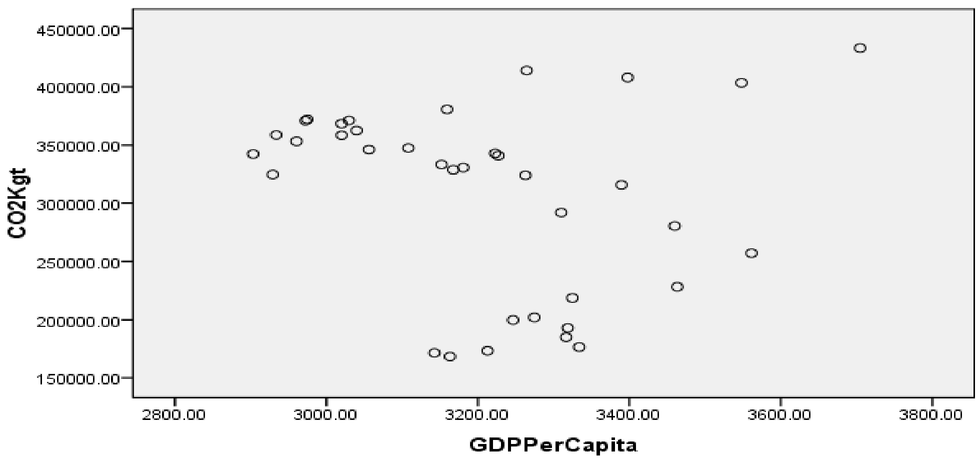

Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

Fig 14: CO2 Emission (Kgt) versus GDP Per Capita in Rawanda




Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

Fig 5: CO2 Emission (Kgt) versus GDP Per Capita in South Africa




Note: GDP Per capita at year 2000 $ prices; CO2 emission in Kgt

# DISCUSSION

The bare results obtained in this study have been presented in previous chapter. However, the inferences are discussed here as under.

Like other empirical studies, this project is also focused on examining the complex relationship between environmental pollution in the form of $CO_2$emission caused by its three major drivers viz. population pressure, economic development and technological advancements.In order to examine their relation in depth, the countries of all three categories of economiesviz. developing, developed and least developed are included. The study is not intended to estimate the absolute impact at a particular point of time but to make a comparative assessment as to which factor causes more damage over a period of time and along the developmental path of a country. And, also, to study the behavior of the mostdamagingfactor along the developmental path of a country so as to find out a solution to contain$CO_2$ emission through policy guidelines.

1. **Selection of variables**

Environment is acomplex phenomenon, so are its studies. Some of the basic questionswhich emerged in the beginningof this studywere: the choice of indicators of environmental health, selection of variables and choice ofrobust and reliable model. It is widely accepted that it is not easy to quantify environmentalhealth. However, there are some indicators which can tell its degradation. Among such indicators is the global warming caused by high emission of GHGs. Amongst all GHGs, $CO_2$emission indicates depletion of resources and fossil fuels causing environmental damage. Both anthropogenic and economic activities release $CO_2$. Thus, the carbon dioxide gas ($CO_2$) is selected as an indicator of environmentaldegradation in this study.

## 2. Selection of model

The only hypothesis which was framed in this study is that economic development in terms of GDP per capita causes more damage to the environment (in form of $CO_2$ emission) than demographic pressure. The moot question was to employ a model which could test this hypothesis. The work done by Molinas (2010); Blodgett and Parker (2010) has been found useful in this regard.

For the last two decades the decomposition form of IPAT model and EKC are being used for air and water pollution studies of this nature. These two models have specifically been found useful in comparative studies. Moreover, the objective was not to assess absolute damage in terms of definite quantities but to compare the three categories of economies of the world.

## 3. Choice of economies

With regard to the choice of economies, it is put on records that the economies selected in this study are the best representatives and most prominent countries in their respective groups. USA, UK, France, Germany, Japan, Italy and Canada are the biggest and most developed economies in the group of developed nations. Similarly, Brazil, Russia, India, China, South Africa, Indonesia and Malaysia are the fastest growing economies amongst the developing countries. Similar is the case for least developed economies.

## 4. Test of hypothesis in IPAT model

The hypothesis has been found true for developing and developed economies as in all developing and developed nations the percentage of Affluence (A’) is highest in the total impact. The deviation is observed only in case of poor countries like Nepal, Liberia, Madagascar and Rwanda which are exactly in consonance with the theory that in the initial stages of development the countries don't have environmental friendly technologies. In these poor counties the percentage of technology (T') is highest in total impact (Table 5 and Fig 4(b)(iii). It is also observed that the poor countries which are about to enter the group of developing nations viz. Bangladesh, Malawi and Kenya are adopting environmental friendly technologies because of which factor 'T' is helping in reduction of total impact (Table 5). Their pattern has been found similar to that of developing economies. However, the proportion of A' factor is highest in terms of contribution to the impact which is 137.22% for USA; 138.21% for Japan; 169.63% for Italy and 100.77% in case of Canada: in Brazil it is 75.84%; India is 75.38%, China 120.88%; South Africa 55.56 %; Indonesia 66.97%; and Malaysia 78.25 %.

**Hence, the hypothesis that economic growth (in terms of GDP per capita) causes more harm to the environment in terms of $CO_2$ emission, holds true for developing and developed economies.**

The technological advancements are contributing for the reduction of impact on $CO_2$ emission as has been seen in the developed economies i.e. UK, France and Germany; and in advanced developing economies like China and Brazil. It is because of the reason that adoption of environmental friendly technologies for the generation of energy and production of consumer goods. However, environmental un-friendly technologies of poor nations like Nepal, Liberia, Madagascar and Rwanda cause more damage to the environment than the other two factors. The technological factor (T') is causing maximum damage which is 50.02% in case of Nepal; 44.83% in case of Liberia; 48.83% in case of Madagascar; and 49.08% in case of Rwanda. It shows that poor counties are least concerned about the use of environmental friendly technologies. Contrary to that UK, France and Germany are effective policies to use clean technologies for the production of energy and consumer goods.

In developing and least developed economies, where affluence is increasing, the impact on environment in terms of $CO_2$emission is also increasing. However, as the economies are becoming more and more developed like that of China and Brazil total impact on environment is becoming smaller.

## 5. Relation between $CO_2$ emission and economic growth (GDP per capita)

Second step in this study is to find a relation between the most harmful factor and $CO_2$ emission. During last two decades Environmental – Kuznets – Curve was widely used in these type of studies. Despite the fact that most of the researchers have already declared that EKC curve does not fit in $CO_2$ emission (Panayotou, 2003), this curve was used to study relationship between $CO_2$ emission and GDP on the ground that there are a large number of countries under study and it was hoped to find any relation of any kind.

It is observed that ideal 'inverted- U' shape curve is not found in any of the counties in case of $CO_2$ emission. However, some interesting relations are evident. Positive relation between $CO_2$ emission and GDP has been found in case of developing economies (i.e. increase in $CO_2$ emission with increase in income) of Asia viz. India, China, Malaysia, Indonesia and more so in case of Bangladesh, Brazil and Nepal. It is also observed that the poor economies which are at the thresh hold of entering into the group of developing nations are also showing this positive relation. On the other hand a negative relation is observed in Germany, UK and France where $CO_2$ emission is decreasing with economic development. Also in these three economies there is no adverse impact on environment as total impact 'I' is negative

(Table 5).As compared to USA, Japan and Canada where their CO2 emission is increasing even at $25,000 to $40,000 per capita GDP, the trends are downwards at even $ 15,000 per capita GDP in UK, France and Germany. It means a country's policies and use of clean technologies are important for factors forcontaining CO2 emission.

Though USA, Japan and Canada are at about $40,000 per capita GDP, their emissions in absolute terms are still increasing. The curves are following 'N' shaped movements. It proves that $CO_2$ emission can only be controlled by environmental policies and with the employment of environmental friendly technologies.

This is interesting to note that economic development does not take care of $CO_2$ emission at its own as was initially envisaged in Environmental – Kuznets – Curve that after attaining a peak the economy automatically moves over to environment friendly path. It can be explained in another way that energy which is the fundamental actor of economic growth is important factor behind the release of $CO_2$. Unless until such technologies are adopted which keeps CO2 emission in check, the environmental damage cannot be controlled.

## 6. Interactions of three factors viz. Population, Affluence and Technology

From the results presented in Table 5, it is amply clear that all the three factors viz. P', A' and T' are contributing to the total impact. The pattern observed in case of seven developed economies is really interesting. It has been found that three economies viz. France, Germany and UK are completely clean as their total impact is -0.27, -1.56 and -0.43 respectively. However, total impact of Canada, USA, Japan and Italy is 2.73, 1.93, 1.90 and 1.11. It means these four countries are still causing damage to the environment. However, if we take a look over technology factor (T') it is clear that values for T’ in all these economies are negative i.e. technology is contributing in lowering total impact. The best technology seems to be of Germany with maximum negative value of -3.18 followed by UK (-2.91) then France (-2.89), USA (-1.58), Japan (-1.14), Italy (-1.05) and then Canada (-0.99). Though all these figures are negative yet Canada, USA, Japan and Italy cause damage by releasing more $CO_2$. It means the technology T’ of USA, Canada, Japan and Italy is not sufficient to ward off the heavy damage being caused by economic growth.

Also the population factor for all these countries is below 1. Hence, it is affluence (A’) and technology (T’) which are responsible for regulation of $CO_2$ emission. Interesting comparison can be made between France and Japan. P’ factor for France is 0.47 and for Japan 0.41 i.e. more or less comparable. Likewise, A’ factor for France is 2.15 and for Japan 2.63. However, T’ factor for France is -2.89 and for Japan -1.14. In our opinion this is the catch point. It is for sure that beyond a level, the population growth cannot be lowered. Rather, it should not be lowered to avoid demographic distortions. However, economic growth and technological factors can be calibrated / standardized to make such policies which could lead to negative impact (I’) i.e. no effect on environment. It is also observed that in developing economies like China, Brazil and Russia, T’ factor is negative, however, because A’ factor is large; it is not possible to contain total impact of $CO_2$ release.

# CONCLUSION

At this juncture of time when the world community is seriously threatened by the vagaries of weather, environmental studies are attracting a great deal of concern. An attempt has been made in this work to study the behavior of $CO_2$ emission in three categories of economies viz. developed, developing and least developed to search a solution for containing $CO_2$ emission. The main objective was to know which of the three factors viz. affluence (economic development), population growth and technological advancements does cause more damage to the environment (in form of $CO_2$ emission) in the present era of globalization and high economic growth. The idea of carrying this study was borrowed from the work of Molinas, (2010); Blodgett and Parker (2010); and Panayotou (2003).

With the help of IPAT model it has been found that in developing and developed economies, economic growth (GDP per capita) is causing more damage to the environment (in terms of $CO_2$ release) than demographic factors (population growth). It can easily be attributed to excessive release of $CO_2$for high economic activities. However, in poor countries like Liberia, Madagascar, Rwanda and Nepal it is the technological factor (T') which is causing severe damage to the environment. It may be because of the reason that neither these countries have environmental friendly technologies norpolicy instruments to check the release of $CO_2$.

It has been found that the economies of Germany, France and UK cause no harm (or say little damage)to the environment by CO2 emission.The value of total impact is negative which shows no harmful effect on environment. Contrary to that the developing economies; least developed; anddeveloped countries like USA, Canada, Japan and Italy are causing heavy damage to the environment. The values of total impact (I) are very high in all these economies.

It has alsobeenobserved that the interactions of all three factors viz. population, economic growth and technology are responsible for regulation of $CO_2$ emission. The population growth has not been found to be very critical. However, GDP per capita (A') and $CO_2$ emission intensity (T') are two crucial factors which could be calibrated / standardized to bring total Impact (I')down. This is what can be made out from the comparison of France, UK and Germany with USA, Canada, Japan and Italy.

It has also been found that $CO_2$ emission does not follow the "Inverted U" shaped Environmental – Kuznets -Curve. Manytypes of relations viz positive, negative, and N shapedhave been observed in the economies under study.

Therewere some expectations in this study to find out prime determining factor of $CO_2$ emission and also the stage of development from where $CO_2$ emission starts declining. However, it is evident that technological factors are important for keeping a check on $CO_2$ emission.It cannot be generalized for $CO_2$emission that after attaining a particular level of development the economies automatically resolve to contain $CO_2$ emissions.

However, it is found beyond any doubt that $CO_2$ emission is a complex phenomenon and requires great deal of empirical studies to evolve and design a model which could predict its behavior with great precision.

# APPENDIX

# APPENDIX – A

**Table 4: Average Annual Growth of Population; GDP (per capita) growth; average annual change in total $CO_2$emission; and $CO_2$ emission intensity.**

| | Average Annual Growth 1971-75 | Average Annual Growth at1976-80 | Average Annual Growth at1981-85 | Average Annual Growth 1986-90 | Average Annual Growth 1991-95 | Average Annual Growth 1996-00 | Average Annual Growth 2001-05 | Average Annual Growth 2006-07 | Overall Average Annual Growth 1971-2007 |
|---|---|---|---|---|---|---|---|---|---|
| **Developing Countries** | | | | | | | | | |
| **1 Brazil** | | | | | | | | | |
| Population (P’) | 1.99 | 1.97 | 1.87 | 1.52 | 1.28 | 1.23 | 1.03 | 0.98 | 1.48 |
| GDP constant 2000 dollar prices (A’) | 9.30 | 5.16 | 2.08 | 0.46 | 2.92 | 1.63 | 2.65 | 6.09 | 3.79 |
| Co2 Emission ( Kgt) | 9.46 | 4.12 | 1.10 | 1.01 | 5.13 | 1.92 | 0.59 | 4.47 | 3.47 |
| Co2 Intensity (T’) | 0.10 | -0.83 | -0.89 | 0.54 | 1.93 | 0.27 | -1.81 | -1.52 | -0.28 |
| | | | | | | | | | |
| **2. Russia** | | | | | | | | | |
| Population (P’) | - | - | - | - | - | -0.19 | -0.38 | -0.28 | -0.29 |
| GDP constant 2000 dollar prices (A’) | - | - | - | - | - | 2.48 | 5.63 | 8.54 | 5.55 |
| Co2 Emission ( Kgt) | - | - | - | - | - | -1.28 | 1.01 | -1.75 | -0.67 |
| Co2 Intensity (T’) | - | - | - | - | - | -3.35 | -3.60 | -9.48 | -5.47 |
| | | | | | | | | | |
| **3 India** | | | | | | | | | |
| Population (P’) | 1.90 | 1.90 | 1.77 | 1.73 | 1.52 | 1.42 | 1.20 | 1.35 | 1.60 |
| GDP constant 2000 dollar prices (A’) | 2.70 | 2.94 | 4.26 | 5.49 | 5.36 | 4.69 | 6.62 | 9.82 | 5.23 |
| Co2 Emission ( Kgt) | 4.50 | 6.43 | 6.17 | 6.26 | 4.94 | 3.68 | 3.44 | 7.18 | 5.33 |
| Co2 Intensity (T’) | 1.59 | 3.04 | 1.58 | 0.61 | -0.33 | -0.82 | -2.39 | -2.40 | 0.11 |
| | | | | | | | | | |
| **4 China** | | | | | | | | | |
| Population (P’) | 1.79 | 1.09 | 1.15 | 1.28 | 0.94 | 0.74 | 0.50 | 0.52 | 1.00 |
| GDP constant 2000 dollar prices (A’) | 4.91 | 7.88 | 11.64 | 6.84 | 12.66 | 7.49 | 9.41 | 14.20 | 9.38 |
| Co2 Emission ( Kgt) | 6.14 | 4.53 | 7.10 | 3.79 | 5.69 | -0.33 | 12.20 | 6.95 | 5.76 |
| Co2 Intensity (T’) | 0.99 | -2.40 | -2.87 | -2.28 | -4.27 | -5.69 | 1.89 | -6.35 | -2.62 |
| | | | | | | | | | |
| **5 South Africa** | | | | | | | | | |
| Population (P’) | 1.88 | 1.83 | 2.16 | 1.92 | 1.77 | 2.00 | 1.02 | 1.10 | 1.71 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| GDP constant 2000 dollar prices (A’) | 2.94 | 2.78 | 0.30 | 1.72 | 1.09 | 2.00 | 3.49 | 5.57 | 2.49 |
| Co2 Emission ( Kgt) | 1.97 | 3.66 | 5.19 | 0.16 | 0.41 | 0.56 | 2.51 | 7.38 | 2.73 |
| Co2 Intensity (T’) | -0.84 | 0.77 | 4.82 | -1.43 | -0.65 | -1.31 | -0.84 | 1.72 | 0.28 |
| | | | | | | | | | |
| **6 Indonesia** | | | | | | | | | |
| Population (P’) | 2.09 | 1.96 | 1.79 | 1.50 | 1.27 | 1.10 | 1.03 | 1.11 | 1.48 |
| GDP constant 2000 dollar prices (A’) | 7.23 | 7.63 | 4.32 | 6.63 | 6.81 | -0.76 | 4.31 | 6.35 | 5.31 |
| Co2 Emission ( Kgt) | 7.68 | 10.67 | 4.21 | 4.57 | 5.03 | 0.38 | 3.60 | 15.84 | 6.50 |
| Co2 Intensity (T’) | 0.33 | 2.20 | -0.09 | -1.55 | -1.33 | 1.19 | -0.58 | 8.93 | 1.14 |
| | | | | | | | | | |
| **7 Malaysia** | | | | | | | | | |
| Population (P’) | 2.02 | 1.96 | 2.23 | 2.45 | 2.15 | 2.04 | 1.78 | 1.75 | 2.05 |
| GDP constant 2000 dollar prices (A’) | 6.68 | 7.00 | 3.99 | 7.55 | 8.71 | 2.98 | 5.08 | 6.48 | 6.06 |
| Co2 Emission ( Kgt) | -19.31 | 940.38 | 3.51 | 8.31 | 15.32 | 0.20 | 6.84 | 4.88 | 5.73 |
| Co2 Intensity (T’) | -19.48 | 691.26 | -0.40 | 0.55 | 4.61 | -2.42 | 1.40 | -1.50 | -0.36 |
| **Developed Countries** | | | | | | | | | |
| **1. USA** | | | | | | | | | |
| Population (P’) | 0.80 | 0.84 | 0.74 | 0.79 | 1.05 | 0.95 | 0.75 | 1.00 | 0.86 |
| GDP constant 2000 dollar prices (A’) | 2.19 | 2.74 | 2.87 | 2.66 | 2.72 | 3.84 | 2.29 | 1.94 | 2.65 |
| Co2 Emission ( Kgt) | 0.14 | 0.15 | -0.21 | 1.66 | 1.42 | 1.56 | 0.75 | 1.37 | 0.86 |
| Co2 Intensity (T’) | -1.85 | -2.27 | -2.70 | -0.88 | -1.14 | -1.91 | -1.37 | -0.56 | -1.58 |
| | | | | | | | | | |
| **2. UK** | | | | | | | | | |
| Population (P’) | 0.11 | 0.04 | 0.08 | 0.20 | 0.21 | 0.25 | 0.38 | 0.65 | 0.24 |
| GDP constant 2000 dollar prices (A’) | 1.75 | 1.26 | 2.51 | 2.64 | 2.00 | 3.02 | 2.08 | 2.68 | 2.24 |
| Co2 Emission ( Kgt) | -1.73 | -0.66 | -0.03 | 0.05 | -0.99 | -1.25 | -0.31 | -2.60 | -0.94 |
| Co2 Intensity (T’) | -3.20 | -1.80 | -2.26 | -2.29 | -2.72 | -3.71 | -2.17 | -5.15 | -2.91 |
| | | | | | | | | | |
| **3. France** | | | | | | | | | |
| Population (P’) | 0.60 | 0.34 | 0.45 | 0.44 | 0.33 | 0.37 | 0.59 | 0.61 | 0.47 |
| GDP constant 2000 dollar prices (A’) | 3.07 | 2.63 | 1.38 | 2.92 | 1.04 | 2.63 | 1.27 | 2.29 | 2.15 |
| Co2 Emission ( Kgt) | -0.67 | -0.01 | -2.37 | 0.70 | -1.61 | -2.09 | 0.33 | -2.40 | -1.01 |
| Co2 Intensity (T’) | -3.25 | -2.33 | -3.51 | -1.94 | -2.51 | -4.16 | -0.88 | -4.58 | -2.89 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **4. Germany** | | | | | | | | | |
| Population (P’) | - | - | - | - | 0.41 | 0.07 | 0.03 | -0.13 | 0.09 |
| GDP constant 2000 dollar prices (A’) | - | - | - | - | 1.21 | 1.87 | 0.35 | 2.66 | 1.52 |
| Co2 Emission ( Kgt) | - | - | - | - | -1.30 | -1.96 | -1.08 | -2.95 | -1.82 |
| Co2 Intensity (T’) | - | - | - | - | -2.37 | -3.50 | -1.40 | -5.46 | -3.18 |
| | | | | | | | | | |
| **5. Japan** | | | | | | | | | |
| Population (P’) | 1.18 | 0.71 | 0.53 | 0.34 | 0.24 | 0.18 | 0.10 | 0.01 | 0.41 |
| GDP constant 2000 dollar prices (A’) | 3.85 | 3.84 | 3.67 | 4.82 | 0.76 | 0.44 | 1.30 | 2.36 | 2.63 |
| Co2 Emission ( Kgt) | 3.09 | 0.99 | -0.04 | 3.73 | 1.47 | -0.59 | 0.33 | 1.50 | 1.31 |
| Co2 Intensity (T’) | -0.64 | -2.39 | -3.14 | -0.87 | 0.69 | -1.01 | -0.91 | -0.84 | -1.14 |
| | | | | | | | | | |
| **6. Italy** | | | | | | | | | |
| Population (P’) | 0.51 | 0.26 | 0.03 | 0.04 | 0.03 | 0.03 | 0.57 | 0.74 | 0.28 |
| GDP constant 2000 dollar prices (A’) | 2.95 | 3.21 | 1.56 | 2.69 | 0.98 | 1.74 | 0.53 | 1.48 | 1.89 |
| Co2 Emission ( Kgt) | 1.97 | 1.18 | -0.31 | 3.20 | 0.13 | 0.89 | 0.92 | -1.89 | 0.76 |
| Co2 Intensity (T’) | -0.85 | -1.75 | -1.74 | 0.45 | -0.81 | -0.78 | 0.38 | -3.32 | -1.05 |
| | | | | | | | | | |
| **7. Canada** | | | | | | | | | |
| Population (P’) | 1.44 | 0.91 | 0.84 | 1.21 | 0.84 | 0.74 | 0.79 | 1.00 | 0.97 |
| GDP constant 2000 dollar prices (A’) | 3.82 | 2.81 | 2.13 | 2.50 | 2.25 | 4.10 | 2.28 | 2.20 | 2.76 |
| Co2 Emission ( Kgt) | 2.53 | 1.46 | -0.68 | 3.25 | 0.48 | 2.97 | 1.24 | 1.85 | 1.64 |
| Co2 Intensity (T’) | -1.08 | -1.18 | -2.54 | 0.66 | -1.59 | -0.93 | -0.93 | -0.35 | -0.99 |
| **Least Developed Countries** | | | | | | | | | |
| **1. Bangla Desh** | | | | | | | | | |
| Population (P’) | 0.81 | 2.38 | 2.27 | 2.20 | 1.80 | 1.61 | 1.31 | 1.13 | 1.81 |
| GDP constant 2000 dollar prices (A’) | -1.31 | 3.23 | 3.12 | 3.04 | 3.99 | 4.64 | 4.75 | 6.43 | 4.17 |
| Co2 Emission ( Kgt) | - | 7.43 | 5.81 | 7.10 | 8.63 | 3.19 | 4.72 | 5.14 | 6.00 |
| Co2 Intensity (T’) | - | 3.61 | 2.32 | 3.52 | 3.86 | -1.18 | -0.02 | -1.21 | 1.56 |
| | | | | | | | | | |
| **2. Nepal** | | | | | | | | | |
| Population (P’) | 1.94 | 1.98 | 1.99 | 2.01 | 2.09 | 2.04 | 1.84 | 1.94 | 1.98 |
| GDP constant 2000 dollar | 2.14 | 1.51 | 3.44 | 3.91 | 4.21 | 4.00 | 2.55 | 3.41 | 3.15 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| prices (A’) | | | | | | | | | |
| Co2 Emission ( Kgt) | 15.56 | 18.44 | 9.84 | -1.98 | 22.37 | 6.02 | -1.27 | 2.75 | 8.96 |
| Co2 Intensity (T’) | 12.11 | 15.74 | 5.45 | -4.93 | 15.00 | 1.68 | -3.39 | -0.64 | 5.13 |
| | | | | | | | | | |
| **3. Kenya** | | | | | | | | | |
| Population (P’) | 3.14 | 3.25 | 3.26 | 3.00 | 2.63 | 2.17 | 2.21 | 2.58 | 2.78 |
| GDP constant 2000 dollar prices (A’) | 6.03 | 6.59 | 1.83 | 4.54 | 1.33 | 1.36 | 3.04 | 7.01 | 3.97 |
| Co2 Emission ( Kgt) | 7.00 | 6.89 | -8.45 | 7.98 | 11.21 | 2.33 | 3.38 | -9.72 | 2.58 |
| Co2 Intensity (T’) | 0.75 | 0.22 | -9.42 | 2.80 | 9.26 | 0.91 | 0.30 | -15.63 | -1.35 |
| | | | | | | | | | |
| **4. Liberia** | | | | | | | | | |
| Population (P’) | 2.41 | 2.53 | 2.24 | -0.85 | 0.03 | 5.84 | 1.66 | 4.93 | 2.35 |
| GDP constant 2000 dollar prices (A’) | 0.59 | 1.09 | -1.42 | -13.04 | -13.48 | 62.66 | -4.61 | 9.40 | 5.15 |
| Co2 Emission ( Kgt) | -0.53 | 7.64 | -12.55 | -6.73 | 3.33 | 5.32 | 9.34 | -10.68 | -0.61 |
| Co2 Intensity (T’) | -1.08 | 6.21 | -11.98 | 18.10 | 51.60 | -13.87 | 18.12 | -18.35 | 6.09 |
| | | | | | | | | | |
| **5. Malawi** | | | | | | | | | |
| Population (P’) | 2.72 | 2.77 | 2.68 | 4.49 | 0.63 | 2.30 | 2.24 | 2.99 | 2.60 |
| GDP constant 2000 dollar prices (A’) | 4.71 | 4.14 | 3.43 | 2.46 | 1.30 | 2.57 | 3.23 | 5.80 | 3.46 |
| Co2 Emission ( Kgt) | 3.07 | 4.40 | -1.58 | 2.12 | 2.11 | 8.97 | 0.14 | -1.37 | 2.23 |
| Co2 Intensity (T’) | -1.33 | 0.22 | -4.27 | -0.31 | 0.76 | 5.67 | -2.66 | -6.78 | -1.09 |
| | | | | | | | | | |
| 6. Madagascar | | | | | | | | | |
| Population (P’) | 2.31 | 2.32 | 2.15 | 2.44 | 2.60 | 2.68 | 2.57 | 3.00 | 2.51 |
| GDP constant 2000 dollar prices (A’) | -0.14 | 2.07 | 0.39 | 2.46 | 1.00 | 3.63 | 1.11 | 6.24 | 2.09 |
| Co2 Emission ( Kgt) | 13.00 | 12.47 | 1.07 | -3.24 | 4.44 | 14.70 | 0.45 | 11.43 | 6.79 |
| Co2 Intensity (T’) | 13.23 | 9.43 | 0.67 | -5.08 | 3.27 | 9.37 | -0.63 | 4.89 | 4.39 |
| | | | | | | | | | |
| **7. Rawanda** | | | | | | | | | |
| Population (P’) | 2.71 | 2.83 | 2.76 | 2.37 | -3.79 | 7.91 | 1.76 | 2.85 | 2.43 |
| GDP constant 2000 dollar prices (A’) | 0.59 | 7.14 | 1.57 | 0.39 | -6.91 | 8.83 | 6.63 | 5.50 | 2.97 |
| Co2 Emission ( Kgt) | 36.47 | 16.99 | 0.49 | 2.82 | -0.58 | 1.74 | 0.00 | 3.72 | 7.71 |
| Co2 Intensity (T’) | 34.85 | 7.26 | -1.01 | 2.39 | 9.67 | -4.91 | -4.98 | -1.68 | 5.20 |

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