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Factor Decomposition of the Increase in Energy Use and CO_2 Emissions in the World, 1990-2015

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Introduction

The United Nations, in 2015, launched the development agenda 'Transforming Our World: 2030 Agenda for Sustainable Development' as a plan of action for people, planet and prosperity (United Nations, 2015). This plan of action, commonly known as the Sustainable Development Agenda is built upon the Millennium Development Agenda which was launched by the United Nations in 2000 (United Nations, 2000). The Sustainable Development Agenda recognises that eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge and an indispensable requirement for sustainable development. This new development agenda is encompassed in 17 goals, commonly nicknamed sustainable development goals (SDGs) and 169 targets to demonstrate the challenge, the scope and the scale of the challenge of sustainable development. These goals and targets are expected to stimulate action in areas of critical importance for the humanity and the planet. Sustainable development, according to the plan of action, is characterised in terms of economic growth, social inclusion and environmental sustainability. Safeguarding the environment is critical to sustainable development as environment provides the resources necessary for survival and subsistence and, at the same time, absorbs the waste generated as the result of resources use and recycles the waste in the usable form. It is argued that resources available through the environment are not inexhaustible which means that there is a limit beyond which the exploitation of natural resources is bound to compromise the ability of future generations to meet their own needs. Similarly, the capacity of the environment to absorb and recycle waste generated through natural resource use is also limited. This means that sustainable development is firmly rooted in the integrity and sustainability of the environment. Sustainable development is not possible without environmental sustainability.

The criticality of environmental sustainability in all discourse of development also stems from the simple fact that life on the planet Earth exists because of the environment. According to the famous Indian mythology, resources necessary to sustain life are *Kshiti* or land; *Jal* or water; *Pavak* or energy; *Gagan* or atmosphere; and *Samir* or air (Ranjan, 2009). The major environmental concerns that the world is facing today are related to these five elements critical for the very existence of life. The primary stress factors that endanger the environment in terms of these five elements are population and economic growth. It is argued that the impact of these stress factors is so profound that it may outpace the potential environmental benefits accruing out of technological advancements and innovations (Dietz, Rosa and York, 2007). It has therefore been emphasised that drastic efforts on a war footing must be made within as little as a decade to curb the devastating effect of population growth and steep increase in per capita consumption on the environment (Ranjan, 2009). The progress in this direction, however, remains far from satisfactory.

The impact of human activity on the environment may be conceptualised in terms of resources use and wastes generated as the result of resources use. The resources use or the resources demand is determined by both the size of the population and per capita resources use or consumption per capita which is an indicator of affluence. The size of the population reflects the extensiveness of resources use while the affluence or the consumption per capita or per capita resources use is an indicator of the intensity of resources use. The two, in combination, determine the total resources use or the total resources demand. The resources demand may be high if the extensiveness of resources demand is low but intensiveness of resources demand is high - small population with high per capita consumption. The resources demand may also be high if the intensiveness of resources demand is low but the extensiveness of the resources demand is high - large population with low per capita consumption. Reducing both, extensiveness and intensiveness of resources demand is therefore necessary to reduce the demand for resources. Further, the waste generated as the result of resources use depends upon man's capacity to transform resources, especially natural resources into usable form. This brings in the issue of technology or the efficiency of the use of resources in analysing the environment impact of population and affluence. This argument emphasises that the impact of human activity on the environment should be analysed in terms of population size, consumption per capita and the efficiency of resources use as first proposed by Ehrlich (1968) and, subsequently, used in many analytical studies that highlighted the environmental impact of population growth and resources use and the role of technology in mitigating this impact (Bargaoui, Liouane, Nouri, 2014; Bongaarts, 1992, Commoner, 1972; 1991; 1992; 1993; Dietz and Rosa, 1994; 1997; Ehrlich, 2008; Ehrlich and Ehrlich, 1991, Ehrlich and Goulder, 2007; Ehrlich and Holdren, 1971; 1972; Gans and Jöst, 2005; Goklany, 2009; Holdren, 1991; Holdren and Ehrlich, 1974; Liddle, 2013; Mooman and Tullis, 1999; O'Neill and Chen, 2002; Preston, 1996; Ranjan, 2009; Rosa, 1997; Shi,2001; 2003; World Bank, 2007; York, Rosa and Dietz, 2003; Zhu and Peng, 2001).

The importance of environmental sustainability in the 2030 Agenda for Sustainable Development of the United Nations is reflected in the Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all; and Goal 13: Take urgent action to combat climate change and its impacts. One of the targets of the Goal 7 is to, double, by 2030, the global rate of improvement in energy efficiency. On the other hand, one of the targets of the Goal 13 is the integration of climate change measures into national policies, strategies and planning. Concerns for addressing issues related to environmental sustainability have been raised at different platforms earlier also including the Rio Declaration on Environment and Development (1992), Programme of Action adopted at the International Conference on Population and Development at Cairo, Egypt in 1994 (UNFPA, 2014) and Kyoto Protocol for reducing greenhouse gases emissions (1997). Environmental sustainability was also one of the eight Goals of the Millennium Development Agenda of the United Nations that was launched in 2000 and that referred to the period 1990-2000. The target 1 of the Goal 7 of the Millennium Development Agenda called for integrating the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources (United Nations, 2000). On the other hand, target 2 of the Goal 7 of the Millennium Development Agenda called for reducing biodiversity loss in terms of a significant reduction by 2010 in CO2 emissions - total, per capita and per unit gross domestic product (GDP) and consumption of ozone-depleting substances, among others.

However, despite explicit commitments made in these and in many other declarations, the primary energy use in the world is estimated to have increased from 8759 million tones of oil equivalent (Mtoe) in 1990 to 13769 Mtoe in 2015 whereas the CO_2 emissions increased from 20,302 million tones (Mt) in 1990 to 31,452 Mt in 2015 (Enerdata, 2017). This increase in resources demand and wastes generated may be attributed to increased use of resources because of the increase in both the number of people on the planet and increase in average resources use per person or consumption per capita. The increase in resources demand and wastes generated through resources use also reflect the effectiveness of energy conservation efforts and efforts directed towards reducing emission of greenhouse gases, notably CO_2.

The above considerations constitute the rationale for the present analysis which is directed towards analysing the environmental impact of population, affluence and technology during the 25 years between 1990 and 2015 in the world, in its seven geo-political regions and in 44 countries which accounted for more than 73 per cent of the world population in 2015. The environmental impact has been measured in terms of the change in the energy use and associated CO_2 emissions between 1990 and 2015. The decomposition approach using the IPAT framework has been used to analyse the contribution of the change in population size, the change in affluence measured in terms of per capita real gross domestic product (GDP) and the change in technology which has been captured through the change in energy intensity of GDP or the energy required to produce unit GDP and the change in the carbon intensity of energy use or the CO_2 emitted for one unit use of energy on the change in the total energy use and total CO_2 emissions in the world between 1990 and 2015. The analysis is expected to provide the empirical evidence for planning and programming interventions directing towards protecting and sustaining the environment.

The paper is organised as follows. The next section of the paper outlines the methodology adopted for analysing the environmental impact of the population, consumption or affluence and technology. We have used a decomposition aaproach following the famous IPAT model for an ex-post analysis of the contributors of the change in the environment impact during the 25 years between 1990 and 2015. The purpose of the decomposition analysis is to expand the understanding about the impact of the change in population, affluence and technology on the environment during the period under reference. Section three describes the data source used in the analysis. We have used the internationally consistent and comparable data prepared for the World Energy Council by EnerData, an independent research and consulting firm which specialises in the analysis and modeling of the global energy markets and its drivers. Section four of the paper presents a snapshot of the change in population, consumption and technology and their environment impact in the 44 countries countries included in the analysis. Results of the decomposition analysis are presented in section five of the paper while the sixth and the last section of the paper summarises the main findings of the analysis and discusses the policy implications of the environmental impact of the change in the population, affluence and technology in the context of sustainable development.

Data Source

The analysis is based on the estimates of total energy consumption and CO_2 emissions prepared by Enerdata, an independent information and consultancy firm, for the World Energy Council, along with estimates of energy intensity of GDP and CO_2 intensity of GDP for the world, for its seven geopolitical regions and for 44 countries for different years of the period 1990 through 2015 (Enerdata, 2017). In addition, the latest population estimates prepared by the United Nations Population Division have also been used in the analysis (United Nations, 2017). The 44 countries included in the present analysis accounted for more than 73 per cent of the world population in 2015 according to the estimates prepared by United Nations Population Division. At the same time, they accounted for almost 87 per cent of the world energy use and almost 92 per cent of the world CO_2 emissions in 2015 according to the estimates prepared by Enerdata. As such, the trend in the energy use and CO_2 emissions in these 44 countries amply reflect the global scenario. The energy use has been defined as the balance of the primary energy production, external energy trade, marine bunkers and stock changes. The total energy use estimated in this manner includes biomass also. Estimates of energy use in the world also include marine bunkers. However, marine bunkers are excluded in estimating energy use in different geo-political regions and countries. As such, sum of the total energy use of the seven geo-political regions of the world is not equal to the estimated energy use for the world as a whole (Enerdata, 2017).

On the other hand, estimates of CO_2 emissions cover emissions from fossil fuel combustion (coal, oil and gas) only. They have been estimated according to the reference approach of the methodology proposed by United Nations Framework Convention for Climate Change (UNFCCC, 2009). In addition, the energy intensity of GDP has been calculated as the ratio of total energy use and the gross domestic product (GDP) measured in terms of purchasing power parity in terms of 2005 US $ so as to remove the impact of inflation. The real GDP estimates reflect differences in general price levels so that the energy intensity of GDP relates the energy use to the real level of economic activity. The energy intensity measures the total amount of energy necessary to generate one unit of real GDP. Similarly, the CO_2 intensity of GDP is measured in terms of the ratio of CO_2 emissions from fuel combustion to the Gross Domestic Product (GDP) measured in constant 2005 US $ purchasing power parities. It measures the CO_2 emitted to generate one unit of GDP. The ratio of the CO_2 intensity of GDP to the energy intensity of GDP gives the carbon intensity of the energy use which reflects the quantity of CO_2 emitted, on average, as the result of the use of one unit of energy. In this sense, it reflects the efficiency in the use of energy. If the carbon intensity of energy use is high, then it reflects poor efficiency of energy use in terms of wastes generated. By contrast, if the carbon intensity of energy consumption is low, then it reflects high efficiency of energy use. From the perspective of environmental sustainability it is desirable that both the energy intensity of GDP and the CO_2 intensity of GDP should decrease to offset the effect of the increase in population and the increase in affluence on the increase in energy use and CO_2 emissions.

Method

Let E denotes the total energy use, C denotes the total CO_2 emissions, P denotes the population size and G denotes the real gross domestic product. Then, total energy use, E, and total CO_2 emissions, C can be written as

$$E = P * (G/P) * (E/G)$$

or $$E = P * I * U \quad (1)$$

Similarly,

$$C = P * (G/P) * (E/G) * (C/E)$$

$$C = P * I * U * T \quad (2)$$

where I is the per capita real GDP or per capita consumption, U is the energy intensity of GDP whereas T is the carbon intensity of energy use. Equations (1) and (2) are the basic identities that have been used in the present analysis. They describe how energy use and CO_2 emissions are related to the size of the population, level of per capita real GDP or the affluence and the state of technology that determines the energy intensity of GDP and CO_2 intensity of GDP and hence carbon intensity of energy use.

Equations (1) and (2) suggest that the contribution of the change in population, change in affluence and change in technology to the change in energy use and CO_2 emissions can be quantified in terms of multipliers, relative change and absolute change. For example, the energy multiplier (m_E) and CO_2 multiplier (m_C) can be decomposed as

$$\begin{aligned} m_E &= \left(\frac{E_2}{E_1}\right) = \left(\frac{P_2}{P_1}\right) * \left(\frac{I_2}{I_1}\right) * \left(\frac{U_2}{U_1}\right) = m_P * m_I * m_U \\ m_C &= \left(\frac{C_2}{C_1}\right) = \left(\frac{P_2}{P_1}\right) * \left(\frac{I_2}{I_1}\right) * \left(\frac{U_2}{U_1}\right) * \left(\frac{T_2}{T_1}\right) = m_P * m_I * m_U * m_T \end{aligned} \quad (3)$$

Equation (3) shows that energy multiplier and CO_2 multipliers are essentially the product of population, affluence and technology multipliers. On the other hand, the relative change, measured in terms of average annual rate of change, in energy use (r_E) and CO_2 emissions (r_C) can be decomposed as,

$$\begin{aligned} r_E &= r_P + r_I + r_U \\ r_C &= r_P + r_I + r_U + r_T \end{aligned} \quad (4)$$

where

$$r_E = \frac{1}{(t_2 - t_1)} \ln\left(\frac{E_2}{E_1}\right), etc.$$

Equation (4) is true by definition and applies to every country so that the naive regression or correlation approaches, which ignore the sum constraint, are potentially problematic in analysing the relative contribution of the inter-country variation in the change in r_P, r_I and r_U to the inter-country variation in the change in r_E and inter-country variation in the change in r_P, r_I, r_U and r_T to the inter-country variation in the change in r_C. An alternative approach (Preston, 1996; Poorter and van der Werf, 1998; Wright and Westoby, 2001) is to decompose the inter-country variance in r_E and r_C as follows:

$$\begin{aligned} Var(r_E) = Var(r_P) + Cov(r_P, r_I) + Cov(r_P, r_U) + \\ Var(r_I) + Cov(r_I, r_P) + Cov(r_I, r_U) + \\ Var(r_U) + Cov(r_U, r_P) + Cov(r_U, r_I) \end{aligned} \tag{5}$$

and

$$\begin{aligned} Var(r_C) = Var(r_P) + Cov(r_P, r_I) + Cov(r_P, r_U) + Cov(r_P, r_T) + \\ Var(r_I) + Cov(r_I, r_P) + Cov(r_I, r_U) + Cov(r_I, r_T) + \\ Var(r_U) + Cov(r_U, r_P) + Cov(r_U, r_I) + Cov(r_U, r_T) + \\ Var(r_T) + Cov(r_T, r_P) + Cov(r_T, r_I) + Cov(r_T, r_U) \end{aligned} \tag{6}$$

where *Var* denotes the variance and *Cov* denotes the covariance. The relative contribution of the inter-country variance in the average annual relative increase in r_P, r_I and r_U to the inter-country variation in the average annual relative increase in r_E may now be obtained as

$$\begin{aligned} &1 = \mathrm{A}(r_P) + \mathrm{A}(r_I) + \mathrm{A}(r_U) \\ &\mathit{and} \\ &1 = \mathrm{B}(r_P) + \mathrm{B}(r_I) + \mathrm{B}(r_U) + \mathrm{B}(r_T) \end{aligned} \tag{7}$$

where

$$\begin{aligned} &\mathrm{A}(r_P) = \frac{Var(r_P) + Cov(r_P, r_I) + Cov(r_P, r_U)}{Var(r_E)}, \mathit{etc.} \\ &\mathit{and} \\ &\mathrm{B}(r_P) = \frac{Var(r_P) + Cov(r_P, r_I) + Cov(r_P, r_U) + Cov(r_P, r_T)}{Var(r_C)}, \mathit{etc.} \end{aligned} \tag{8}$$

There are two ways, the inter-country variance in a component of r_E or r_C can make a small contribution to the inter-country variance in r_E or r_C. First, the component varies little across countries, and so the variance and covariance terms in equations (5) and (6) are small. Second, the component varies across countries, but the covariance terms are negative and so the sum of the variance and covariance terms is small. In the second case, equations (5) and (6) may not reflect the true importance of the inter-country variance in the components of r_E and r_C in explaining the inter-country variance in r_E and r_C

respectively. This problem may be addressed by using absolute values of the covariance terms instead of their actual values (Horvitz et al, 1997; Rees et al, 2010: Rees et al, 1996) so that the importance of the inter-country variance in the components of r_E and r_C to the inter-country variance in r_E and r_C respectively may be obtained as

$$1 = \Delta(r_P) + \Delta(r_I) + \Delta(r_U)$$
$$\Delta(r_P) = \frac{Var(r_P) + |Cov(r_P, r_I)| + |Cov(r_P, r_U)|}{S}, etc. \tag{9}$$

and

$$1 = \Lambda(r_P) + \Lambda(r_I) + \Lambda(r_U) + \Lambda(r_T)$$
$$\Lambda(r_P) = \frac{Var(r_P) + |Cov(r_P, r_I)| + |Cov(r_P, r_U)| + |Cov(r_P, r_T)|}{V}, etc. \tag{10}$$

where the normalising constant S in equation (9) and V in equation (10) are the sum of the absolute values of the terms on the right-hand side of equations (5) and (6) respectively and are different from $Var(r_E)$ and $Var(r_C)$. Equations (9) and (10) explicitly allow for the fact that the relative increase in E is the weighted sum of the relative increase in P, I and U whereas the relative increase in C is the weighted sum of the relative increase in P, I, U and T. It permits exploring the relative importance of the increase in population, increase in the affluence measured in terms of per capita real GDP and technology measured in terms of energy intensity of real GDP and carbon intensity of energy consumption in the increase in total energy consumption and CO_2 emissions.

One limitation of equations (3) and (4) is that they treat the change in the three components - population, affluence and technology - independent of each other in explaining the change in energy use and CO_2 emissions. It is however logical to argue that the change in one of the three factors that determine energy use and CO_2 emissions, also has an impact on the change in other factors that influence energy use and CO_2 emissions. However, equation (3) and (4) do not take into account the interaction between population, affluence and technology in explaining the change in energy use and CO_2 emissions. To this end, and following Kim and Strobino (1984), the absolute increase in the energy use and the absolute increase in the total CO_2 emissions can be decomposed as follows:

$$\begin{aligned}\nabla E = E_2 - E_1 &= (P_2 * I_2 * U_2) - (P_1 * I_1 * U_1) \\ &= (P_2 - P_1) * I_1 * U_1 + P_1 * (I_2 - I_1) * U_1 + P_1 * I_1 * (U_2 - U_1) + \\ &\quad (P_2 - P_1) * (I_2 - I_1) * U_1 + (P_2 - P_1) * I_1 * (U_2 - U_1) + \\ &\quad P_1 * (I_2 - I_1) * (U_2 - U_1) + \\ &\quad (P_2 - P_1) * (I_2 - I_1) * (U_2 - U_1) \\ &= d_P + d_I + d_U + d_{PI} + d_{PU} + d_{IU} + d_{PIU}\end{aligned} \tag{11}$$

and

$$
\begin{aligned}
\nabla C = C_2 - C_1 &= (P_2 * I_2 * U_2 * T_2) - (P_1 * I_1 * U_1 * T_1) \\
&= (P_2 - P_1) * I_1 * U_1 * T_1 + P_1 * (I_2 - I_1) * U_1 + \\
&\quad P_1 * I_1 * (U_2 - U_1) * T_1 + P_1 * I_1 * U_1 * (T_2 - T_1) + \\
&\quad (P_2 - P_1) * (I_2 - I_1) * U_1 * T_1 + \\
&\quad (P_2 - P_1) * I_1 * (U_2 - U_1) * T_1 + \\
&\quad (P_2 - P_1) * I_1 * U_1 * (T_2 - T_1) + \\
&\quad P_1 * (I_2 - I_1) * (U_2 - U_1) * T_1 + \\
&\quad P_1 * (I_2 - I_1) * U_1 * (T_2 - T_1) + \\
&\quad P_1 * I_1 * (U_2 - U_1) * (T_2 - T_1) + \\
&\quad (P_2 - P_1) * (I_2 - I_1) * (U_2 - U_1) * T_1 + \\
&\quad (P_2 - P_1) * (I_2 - I_1) * U_1 * (T_2 - T_1) + \\
&\quad (P_2 - P_1) * I_1 * (U_2 - U_1) * (T_2 - T_1) + \\
&\quad P_1 * (I_2 - I_1) * (U_2 - U_1) * (T_2 - T_1) + \\
&\quad (P_2 - P_1) * (I_2 - I_1) * (U_2 - U_1) * (T_2 - T_1) \\
&= g_P + g_I + g_U + g_T + g_{PI} + \\
&\quad g_{PU} + g_{PT} + g_{IU} + g_{IT} + g_{UT} + \\
&\quad g_{PIU} + g_{PIT} + g_{PUT} + g_{IUT} + g_{PIUT}
\end{aligned}
\tag{12}
$$

Equations (11) and (12) present comprehensive, path-independent decomposition formula for analysing the change in the energy consumption and CO_2 emissions in terms of the change in population, affluence and technology. The formula is path independent as all factors influencing energy consumption and CO_2 emissions are treated symmetrically so that contribution of one factor does not depend on the order in which different factors are introduced in the model (Biemen, 2012). The formula contains both ceteris paribus effects of the change in population, affluence and technology and interaction effects of any subset of them, and therefore, helps in understanding direct and indirect environmental effects of the three factors.

It is obvious from equations (11) and (12) the change in the energy use and CO_2 emissions is contingent upon the balance between the contribution of factors that leads to an increase and factors that lead to a decrease in energy use and CO_2 emissions. From the environmental perspective which emphasises energy conservation and reduction in the emission of greenhouse gases, this balance may be captured through the offset ratio (OR) which is defined as minus times ratio of total decrease to total increase in energy use and CO_2 emissions attributed to the change in different factors as revealed through the decomposition analysis (World Bank, 2007). When $OR=1$, the increase in energy use or CO_2 emissions attributed to the change in some factors is offset fully by the decrease in energy use and CO_2 emissions attributed to the change in other factors. When $OR<1$, the decrease offsets only a part of the increase and when $OR>1$, the decrease more than offsets the increase in energy use and CO_2 emissions.

Trends in Energy Use and CO_2 Emissions

The energy use in the world is estimated to have increased by 5010 million tonnes of oil equivalent (Mtoe) or by more than 57 per cent from 8759 Mtoe in 1990 to 13769 Mtoe in 2015 (Figure 1) whereas CO_2 emissions are estimated to have increased by 11150 million tonnes (Mt) or by around 55 per cent from 20302 Mt in 1990 to 31452 Mt in 2015 (Figure 2). In terms of relative change, world energy use increased at an average annual rate of 2.089 per cent per year during 1990-2015 whereas CO_2 emissions increased at an average annual rate of 2.117 per cent per year (Table 1). Both energy use and CO_2 emissions increased more rapidly during the period 2000-2010 compared to the period 1990-2000 but there had been a considerable slowdown in the increase in both energy use and CO_2 emissions after 2010. The slowdown in the increase in energy use and in CO_2 emissions can also be witnessed in all geo-political regions of the world, although the pace of slowdown varied across regions. In Europe, CIS and North America, energy use decreased, instead increased, after 2010 whereas CO_2 emissions decreased in Pacific region also in addition to Europe, CIS and North America.

The increase in energy use and CO_2 emissions has been disproportionately distributed across geo-political regions. More than 71 per cent of the increase in energy use and close to 90 per cent of the increase in CO_2 emissions in the world during 1990-2015 was confined to Asia alone. In 1990, energy use in Asia accounted for around 25 per cent of the world energy use and around 23 per cent of the world CO_2 emissions. These proportions increased to 42 per cent and 26 per cent respectively in 2015. Besides Asia, the Middle-East is the only region of the world where the increase in energy use and CO_2 emissions accounted for more than 10 per cent of the global increase in energy use and CO_2 emissions during 1990-2015. By contrast, energy used decreased in CIS whereas CO_2 emissions decreased in CIS as well as in Europe during the period under reference.

The very rapid increase in both energy use and CO_2 emissions in the world and in Asia may be attributed to very rapid increase in energy use and CO_2 emissions in China, the most populous country of the world. China accounted for more than 45 per cent of the increase in energy use and more than 59 per cent of the increase in CO_2 emissions in the world during 1990-2015. In 1990, energy use in China was only around 10 per cent of the world energy use and almost 11 per cent of world CO_2 emissions. These proportions increased to 23 per cent and 28 per cent respectively in 2015. By comparison, the increase in energy use in India, the second most populous country of the world, accounted for only 11 per cent of the increase in world energy use and 13 per cent of the increase in world CO_2 emissions during the same period. In 1990, energy use in India was just around 4 per cent of the world energy use and only around 2.5 per cent of world CO_2 emissions. In 2015, the energy use in India was only around 6.3 per cent of the total energy use in the world whereas the CO_2 emissions in the country were also around 6.3 per cent of the total CO_2 emissions in the world.

Tables 1 also indicate that nearly sixty per cent of the increase in the energy use and almost two-third of the increase in CO_2 emissions in the world during 1990-2015 were confined to the period 2000-2010. However, in Europe, North America and Pacific, energy use and CO_2 emissions did not increase throughout the period under reference. In Europe, energy use started decreasing after 2006 and in North America, after 2007. In CIS, on the other hand, energy use decreased, instead increased, during 1990 through 1998 but increased during 1998-2012 and started decreasing again after 2012. In other regions of the world, on the other hand, energy use increased throughout the period under reference. A similar trend may also be seen in case of CO_2 emissions. Moreover, in 30 of the 44 countries included in the present analysis, the increase in energy use slowed down during 2000-2015 whereas in 14 countries it turned negative meaning a decrease in energy use. Similarly, CO_2 emissions decreased in 16 countries while the increase slowed down in 19 countries during 2000-2015.

In per capita terms, energy use in the world increased from 1649 in 1990 to 1873 Kg of oil equivalent (Koe) per capita in 2015 (Figure 3) whereas CO_2 emissions increased from 3822 in 1990 to 4278 Kg per capita in 2015 (Figure 4). Increase in both per capita energy use and per capita CO_2 emissions was the most rapid in Middle-East whereas per capita energy use decreased in Europe, CIS and North America while per capita CO_2 emissions decreased in Europe, CIS, North America and Pacific (Table 2). Although, per capita energy use and CO_2 emissions remained the highest in North America but the lowest in Africa throughout the period under reference, yet, the rank of Pacific and Middle-East regions improved while that of Europe, CIS, Latin America and Asia gone down over time.

Among the 44 countries, per capita energy use was the highest in United Arab Emirates but the lowest in India in 1990 whereas per capita CO_2 emissions were the highest again in United Arab Emirates but the lowest in Nigeria. However, in 2015, Kuwait topped the list in both per capita energy use and per capita CO_2 emissions whereas per capita energy use remained the lowest in India while per capita CO_2 emissions remained the lowest in Nigeria. The increase in per capita energy use and CO_2 emissions was however the most rapid in China. On the other hand, both per capita energy use and per capita CO_2 emissions decreased in 17 countries with Ukraine recording the most rapid decrease in both. Out of these 17 countries, 11 are in Europe, 4 are CIS countries and one each are in Asia and Middle-East. In Japan, per capita energy use decreased but per capita CO_2 emissions increased whereas in New Zealand, per capita energy use increased but per capita CO_2 emissions decreased during the period under reference.

Factors Influencing Energy Consumption and CO_2 Emissions

The energy use and CO_2 emissions are primarily influenced by the size of the population and the level of affluence which is commonly measured in terms of per capita real GDP. The two, in combination, determine the energy intensity which is also viewed as an index of energy conservation. Table 3 presents estimates of population size and per capita real GDP in terms of 2005 US$ ppp for the world and for its different geo-political regions for years 1990, 2000, 2010 and 2015. The population of the world increased by 2040 million or by more than 38 per cent at an average annual rate of increase of 1.3 per cent per year during the period 1990-2015. Population growth appears to have slowed down during the period 2010-2015 when world population increased at an average annual rate of 1.18 per cent per year compared to the period 1990-2000 when the world population increased at an average annual rate of 1.42 per cent per year. Population growth has been the most rapid in Africa (2.525 per cent per year) so that Africa's population increased by 88 per cent during the period under reference. By contrast, population growth was the slowest in CIS (0.101 per cent per year) so that the population of this region of the world increased by only about 2.6 per cent between 1990 and 2015. In Europe and North America also, population growth has been very slow but very rapid in the Middle-East.

On the other hand, per capita real GDP (2005 US$ ppp) in the world increased from 7645 in 1990 to 12783 in 2015. In other words, the per capita GDP in the world increased more than two-third during the period under reference at an average annual rate of growth of 2.06 per cent per year. The per capita real GDP, however, varied widely across different geo-political regions ranging from 4677 in Africa to 27960 in Europe in 2015. Besides Africa, Asia is the only other region of the world where the per capita real GDP was estimated to be less than 10,000 in 2015. The rate of increase in per capita real GDP also varied widely across different geo-political regions with the increase being the slowest in CIS and very slow Africa but very rapid in Asia where per capita real GDP is estimated to have increased at a whopping average annual rate of increase of more than 4.4 per cent per year during the period under reference.

The increase in population and in real GDP per capita during the period under reference, also varies across the 44 countries included in the analysis. The population growth during 1990-2015 was the most rapid in United Arab Emirates with an average annual rate of increase of 6.37 per cent per year. Population also increased at an average annual rate of more than 2 per cent per year in Kuwait, Malaysia, Nigeria and Saudi Arabia. By contrast, the average annual population growth was less than 1 per cent per year during the period under reference in 22 countries whereas in three countries - Romania, Russia and Ukraine - population decreased, instead increased, during the period under reference according to the latest estimates prepared by the United Nations Population Division. On the other hand, the increase in per capita real GDP was the most rapid in China with an average annual rate of increase of more than 8 per cent per year. The very rapid increase in the per capita real GDP in China appears to be the reason behind the very rapid increase in per capita real GDP in Asia. There are in all 9 countries where per capita real GDP increased at an average annual rate of at least 3 per cent per year during the period under reference. At the same time, there are seven countries where the growth of real GDP was very slow - less than 1 per cent per year - whereas, in two countries - United Arab Emirates and Ukraine - per capita real GDP decreased, instead increased, during the period under reference.

The trend in the energy intensity and the carbon intensity of GDP in the world and in its different geo-political regions is presented in table 4 which shows that both energy intensity and carbon intensity of GDP and the resulting carbon intensity of energy use in the world decreased during 1990-2015. Among different geo-political regions of the world, both energy intensity and carbon intensity of GDP was the highest in CIS in 1990 as well as in 2015 but the lowest in Africa. Moreover, the energy intensity of GDP decreased in all geo-political regions except Middle-East whereas the carbon intensity of GDP increased in Latin America, Asia and Middle-East during this period. The decrease in energy intensity and carbon intensity of GDP has been the most rapid in CIS but the slowest in Latin America. Among the 44 countries, the decrease in both energy intensity and carbon intensity of GDP was the most rapid in Uzbekistan. By contrast, there are eight countries where the energy intensity of GDP increased but there are nine countries where the carbon intensity of GDP increased during the period under reference with the increase in both energy intensity and carbon intensity of GDP being the highest in Iran.

Multipliers of Energy Use and CO_2 Emissions

Equation (3) suggests that energy use multiplier (m_E) in a given period is the product of population multiplier (m_P), income per capita multiplier (m_I) and energy intensity of GDP multiplier (m_U) during that period. On the other hand, CO_2 emissions multiplier (m_C) is the product of m_P, m_I, m_U and carbon intensity of energy use multiplier m_T. A multiplier greater than 1 indicates the increase while a multiplier less than 1 indicates the decrease. When the multiplier is equal to 1, there is neither increase nor decrease or there is no change. Moreover, the combined multiplier of more than one factors is the product of multiplier of each factor.

Table 5 presents values of m_E, m_C, m_P, m_I, m_U and m_T for the world and for its geo-political regions for different durations of the period 1990-2015. The world energy use multiplied by 1.565 times between 1990 and 2015. It would have actually multiplied by 2.316 times because of the increase population and increase in per capita real GDP. However, the multiplier of energy intensity of GDP was less than 1 during this period so that the energy use multiplied by only 1.565 times. Similarly, the multiplier of carbon intensity of energy use was also less than 1 during this period so that the multiplier of CO_2 emissions was only 1.549. In other words, the increase in population and the increase in per capita real GDP during the period under reference would have increased the energy use in the world to 19816 Mtoe and CO_2 emissions to 47011 Mt. However, the decrease in the energy intensity of GDP during this period resulted in a decrease in the energy use by 6422 Mtoe so that the actual increase in the energy use during 1990-2015 was 13394 Mtoe. Similarly, the decrease in the energy intensity of GDP resulted in a decrease of 15234 Mt while the decrease in the carbon intensity of energy use resulted in a decrease of 325 Mt in CO_2 emissions between 1990 and 2015 whereas the increase in population and the increase in per capita real GDP resulted in an increase of 26709 Mt so that the net increase in CO_2 emissions during 1990-2105 was 11150 Mt. It is however obvious from table 8 that the environmental effects of technology reflected through the decrease in energy intensity of GDP and decrease in CO_2 emissions per unit energy use had been able to compensate only partially the environmental effects of the increase in population and the increase in affluence as measured in terms of per capita real GDP. The joint multiplier of population increase, increase in per capita real GDP and energy intensity of GDP was the highest in the Middle-East but the lowest in CIS. In the Middle-East, all the three factors contributed to increase the energy use whereas in CIS because of a rapid decrease in the energy intensity of GDP. In case of CO_2 emissions also, the multiplier effects of population growth, increase in per capita real GDP, energy intensity of GDP and carbon intensity of energy use was the highest in the Middle-East but the lowest in CIS. In the Middle-East and in Asia, CO_2 emissions multiplied by more than three times between 1990 and 2015 whereas in CIS and Europe, CO_2 emissions decreased during the period under reference. The carbon intensity of energy use, however, increased in Asia and Latin America but decreased only marginally in North America, Pacific, Africa and Middle-East.

Population, affluence and technology multipliers of energy use and CO_2 emissions vary widely across the 44 countries included in the present analysis resulting in wide variation in the change in energy use and CO_2 emissions over time across countries. The population was less than 1 during 1990-2015 in three countries meaning that the population decreased, instead increased, in three countries. Similarly, the per capita real GDP multiplier was less than 1 in two countries whereas the energy intensity of GDP multiplier was less than 1 in 35 countries meaning a decrease in the energy required in producing one unit of real GDP. However, there are 9 countries where the energy intensity of GDP multiplier was more than 1 which implies that the energy required in producing one of GDP in these countries increased during the period under reference. On the other hand, the carbon intensity of energy use multiplier was more than 1 in 13 countries which means that the CO_2 emitted in the use of one unit of energy in these countries increased in 2015 as compared to that in 1990. Brazil is the only country where both energy intensity of GDP multiplier and the carbon intensity of energy use multiplier was more than 1 during the period under reference. A carbon intensity of energy use multiplier greater than 1 implies that more CO_2 was being emitted per one unit of energy use in 2015 as compared to that in 1990.

Decomposition of the Relative Change in Energy Use and CO_2 Emissions

Table 6 presents average annual rate of change in energy use (r_E), population (r_P), per capita real GDP (r_I), energy intensity of GDP (r_U), carbon intensity of energy use (r_T) and CO_2 emissions (r_C) in the world and in its different geo-political regions and selected countries during the period 1990-2015. The energy use in the world increased at an average annual rate of 1.792 per cent per year during the period under reference as the result of the increase in population at the rate of 1.300 per cent per year, increase in per capita real GDP at the rate of 2.059 per cent per year and the decrease in the energy intensity of GDP at the rate of 1.567 per cent per year. On the other hand, CO_2 emissions in the world increased at the rate of 1.751 per cent per year because, the carbon intensity of energy use decrease marginally at the rate of 0.041 per cent per year. Obviously, technological change as reflected in terms of the energy intensity of GDP and carbon intensity of energy use could not be able to compensate for the increase in the energy use and CO_2 emissions that may be accounted by the change in population and the change in the affluence.

The scenario in different geo-political regions was however different. In Europe, there was practically little increase in the energy use because the rate of decrease in energy intensity of GDP almost nearly compensated the population growth rate and rate of increase in per capita real GDP. On the other hand, the rate of change in both energy use and CO_2 emissions was negative in CIS because the rate of decrease in the energy intensity of GDP and the rate of decrease in the carbon intensity of energy use far outweighed population growth rate and rate of increase in per capita real GDP. By contrast, the rate of increase in energy use and in CO_2 emissions was the highest in the Middle-East because the energy intensity of GDP increased, while population growth was very rapid during this period. In Asia, very high rate of increase in energy use and CO_2 emissions is attributed to very rapid increase in per capita real GDP whereas high rate of increase in energy use and CO_2 emissions in Africa appears to be the result of rapid population growth.

Among different countries, contribution of the rate of change in population, per capita real GDP, energy intensity of GDP and carbon intensity of energy use to the change in energy use and CO_2 emissions varies widely. In majority of the countries, however, the rate of decrease in energy intensity of GDP and the rate of decrease in carbon intensity of energy use could not compensate the rate of increase in per capita real GDP and population growth rate. This means that, in these countries, energy conservation and greenhouse gases reduction efforts had not been able to compensate the environmental impact of population growth and increase in affluence.

Table 7 shows the decomposition of the inter-country variation in the rate of change in energy use and CO_2 emissions into inter-country variation in the rate of change in population, per capita real GDP, energy intensity of GDP and carbon intensity of energy use. More than one third of the inter-country variance in the rate of change in energy use is attributed to inter-country variance in population growth rate whereas the rate of change in energy intensity of GDP accounts for almost 40 per cent of the inter-country variance. On the other hand, inter-country variance in the rate of change in the carbon intensity of energy use contributes only marginally to the inter-country variance in the rate of change in CO_2 emissions. It may however be noted from the table that a number of covariance terms terms are negative. A negative covariance masks the importance of a factor in explaining the variability in energy use and CO_2 emissions. When only the absolute values of covariance terms are taken into consideration, inter-country variation in the rate of change in per capita real GDP turns out to be the most important factor in deciding the inter-country variation in the rate of change in energy use and CO_2 emissions during the period under reference and the rate of change in the population growth rate turns out to be the least important. It may also be observed from table that inter-country variation in the rate of change in carbon intensity of energy use has hardly been relevant to the inter-country variation in the rate of change in CO_2 emissions.

Decomposition of the Absolute Change in Energy Use and CO_2 Emissions

Decomposition of the absolute change in energy use and CO_2 emissions is presented in table 8. The energy use in the world increased by 4837 Mtoe during the period under reference. The ceteris paribus or direct effect of population growth resulted in an increase of 3286 Mtoe in the energy use while the ceteris paribus effect of the increase in affluence resulted in increase of 5752 Mtoe in the energy use. Finally, the effect of technology advancement resulted in a decrease of 2770 Mtoe in the energy use. In addition, indirect effects of population growth, increase in affluence and technological change resulted in a decrease in the energy use by 1442 Mtoe. Similarly, CO_2 emissions in the world increased by 11150 Mt. The direct effect of population growth resulted in an increase of 7797 Mt while that of increase in affluence resulted in an increase of 13647 Mt in CO_2 emissions. The increase in CO_2 emissions as the result of population growth and increase in affluence was offset by a decrease of 6572 Mt resulting from the in the decrease in energy use in producing one unit of GDP a decrease of 208 Mt resulting from the decrease in CO_2 emitted in using one unit of energy. At the same time, interaction effects of population growth, increase in affluence and improvement in technology resulted in a decrease of only 993 Mt in CO_2 emissions. The offset ratio (OR) is 0.570 which implies that the decrease in energy use attributed to the decrease in the energy required to produce one unit of GDP either directly or indirectly was able to offset only 57 per cent of the increase in the energy use attributed to population growth and increase in affluence. In case of CO_2 emissions, OR is only 0.442. Obviously, the decrease in the energy intensity of GDP and carbon intensity of energy use could offset less than half of the increase in CO_2 emissions attributed to population growth and increase in affluence.

Across different geo-political regions, OR ranges from 0 in Middle-East to 2.718 in CIS in case of energy use and from just 0.045 in Middle-East to 4.26 in CIS in case of CO_2 emissions. In case of energy use, CIS is the only geo-political region where $OR>1$ whereas in case of CO_2 emissions, $OR>1$ in CIS and in Europe. In North America also, OR is very close to 1 in case of both energy use and CO_2 emissions. In other words, in CIS, Europe and North America, technology had more or less been able to offset the environmental effects of population growth and increase in affluence during the period under reference. This had, however, not been the case in Africa, Asia and Pacific where $OR<1$ during the period under reference. On the other hand, none of the three factors contributed to the decrease in energy use in Middle East so that $OR=0$ and there was no offsetting effect in case of energy use. However, the carbon intensity of energy use decreased marginally in this region so that OR was marginally larger than zero in case of CO_2 emissions.

Among the 44 countries, OR is found to be the highest in Ukraine in case of both energy use and CO_2 emissions because all the factors that determine energy use and CO_2 emissions decreased in the country during the period under reference so that increase in both energy use and CO_2 emissions was because of first order interaction efforts only (Table 9). In addition, $OR>1$ in eight countries in case of energy use and 12 countries in case of CO_2 emissions. In all these countries, the decrease in the energy intensity of GDP was primarily responsible for the decrease in energy use and reduction in CO_2 emissions. At the same time, in two countries - Romania and Russia - decrease in population also contributed to the decrease in energy use and reduction in CO_2 emissions. On the other hand, OR=0 in eight countries in case of energy use and in two countries in case of CO_2 emissions. In these countries, none of the three factors determining energy use and four factors determining CO_2 emissions decreased during 1990-2015 and so that there was no offsetting effect.

Table 9 also indicates that China, the most populous country of the world, alone, accounted for almost 46 per cent of the increase in world energy use and 59 per cent of the increase in world CO_2 emissions during the period under reference. The very rapid increase in energy use and CO_2 emissions in China had primarily been due to very rapid increase in affluence. The per capita real GDP in China increased from 1304 2005 US$ ppp in 1990 to 11737 in 2015 whereas China's population increased from 1.172 billion to 1.379 billion during this period. Although, the energy intensity of GDP in the country decreased rapidly from 0.569 Koe in 1990 to 0.188 Koe in 2015, yet the carbon intensity of energy use increased from 2.528 K per one Koe of energy use to 2.854 K per one Koe of energy use during this period. In addition to China, India, the second most populous country of the world, is the only other country which accounted for more than 10 per cent of the world energy increase and CO_2 emissions. Between 1990 and 2015, India's population increased from 0.870 billion to 1.309 billion, per capita real GDP increased from 1576 2005 US$ ppp to 5046 2005 US$ ppp, energy intensity of GDP decreased from 0.223 Koe per unit GDP to 0.128 Koe but the carbon intensity of energy use increased from 1.679 K to 2.380. Unlike China, population growth in India contributed substantially to the increase in energy use and CO_2 emissions in the country. This means that the two most populous countries of the world accounted for around 57 per cent of the increase in world energy use and about 72 per cent of the increase in world CO_2 emissions between 1990 and 2015, although they accounted for only about 33 per cent of the increase in world population during 1990-2015.

Discussions and Conclusions

The analysis highlights the fact that, at the global level, the negative environmental effects of population growth and increase in affluence could not be fully offset by the positive environmental effects of technology advancement, although the positive environmental effects of technology advancement have been confined to energy efficiency of GDP only. There appears to be little impact of technology advancement on the carbon intensity of energy use. The analysis presented here raises concerns about the belief that technology advancement will be able to mitigate the negative environmental effects of population growth and increase in affluence particularly when increase in affluence is universally recognised as the indicator of social and economic development and improvements in the quality of life. It is obvious that efforts directed towards social and economic progress are bound to result in substantial increase in the use of resources and resulting waste generation. The problem may be compounded further because of the continued increase in population despite the decrease in fertility. Most of the increase in population that the world is witnessing now is primarily because of momentum resulting from the past population dynamics. It is well known that even if the replacement fertility is achieved today and sustained in future, the world population will continue to increase for at least one generation because of the in-built momentum for growth. The impact of this momentum on future population growth cannot be eliminated. It can, at best be extended to lessen its negative environmental effects.

An important issue in technology-based approach of mitigating the environmental effects of population growth and increase in affluence is that there is a cost involved in technology advancement and technology upgradation necessary to offset the environmental effects of increased affluence and increasing population and this cost increases hyperbolically with advances in technology. This means that technology-based approach to addressing environmental concerns is bound to lead to increasing disparities in social and economic development and increase in the gap in the quality of life of the rich and the poor as the poor and the under-privileged population may remain bereft of the dividends of technology advancement which come with a cost. Moreover, the increasing rich and poor gap in almost all aspects of social and economic development will also limit the positive environmental effects of technology advancement. Glimpses of such a scenario are also reflected from the present analysis as technology advancement appears to have largely offset the negative environmental effects of population growth and increase in affluence in the so called developed countries but not in developing and the least developed countries.

The 2030 sustainable development agenda of the United Nations characterises sustainable development in terms of economic growth, social inclusion and environmental sustainability. The present analysis indicates that a technology driven approach to ensure environmental sustainability may lead to economic and social disparities that may have jeopardising impact on economic growth and social inclusion dimensions of the sustainable development agenda. A more pragmatic approach may be integrating efforts directed towards pursuing economic growth, securing social inclusion and protecting the environment. Such an integrated approach requires recognising the interactions between population, affluence and technology in the contemporary context. Unfortunately, the 2030 sustainable development agenda pays only a lop-sided attention to these interactions which are the key to sustaining life on the planet Earth.

References

Aguir Bargaoui S, Liouane N, Nouri FZ (2014) Environmental impact determinants: an empirical analysis based on the STIRPAT model. *Procedia - Social and Behavioral Sciences* 109: 449-458.

Biemen M (2012) Additive decomposition with interaction effects. Bonn, Institute for the Study of Labor (IZA). Discussion Paper No. 6730.

Bongaarts J (1992) Population growth and global warming. *Population and Development Review* 18(2):299-319.

Commoner B (1972) The environmental cost of economic growth. In RG Ridkar (Ed) *Population, Resources and the Environment*. Washington DC, US Government Printing Office.

Commoner B (1991) Rapid population growth and environmental stress. *International Journal of Health Services* 21(2):199-227.

Commoner B (1992) *Making Peace with the Planet*. New York, New Press.

Commoner B (1993) Population, development and the environment: trends and key issues in the developed countries. *International Journal of Health Services* 23(3):519-539.

Dietz T, Rosa EA (1994) Rethinking the environmental effects of population, affluence and technology. *Human Ecology Review* 1:277-300.

Dietz T, Rosa EA (1997) Effects of population and affluence on CO_2 emissions. *Proc Natl Acad Sci USA* 94:175–9.

Dietz T, Rosa EA, York R (2007) Driving the human ecological footprint. *Frontiers in Ecology and Environment* 5(1):13-18.

Ehrlich PR (1968) *The Population Bomb*. New York, Ballantine Books.

Ehrlich PR (2008) Demography and policy: a view from outside the discipline. *Population and Development Review* 34: 103–113.

Ehrlich PR, Ehrlich AH (1991) *Healing the Planet*. Reading, MA, Addison-Wesley.

Ehrlich PR, Goulder LH (2007) Is current consumption excessive? A general framework and some indications for the United States. *Conservation Biology* 21: 1145–1154.

Ehrlich PR, Holdren JP (1971) Impact of Population Growth. *Science* 171: 1212–1217.

Ehrlich PR, Holdren JP (1972) Impact of Population Growth. In RG Ridkar (Ed) *Population, Resources and the Environment*. Washington DC, US Government Printing Office.

Enerdata (2017) *Global Energy Statistical Yearbook*. https://yearbook.enerdata.net. Retrieved 20 April 2018.

Gans O, Jöst F (2005) Decomposing the impact of population growth on environmental deterioration. Heidelberg, University of Heidelberg, Department of Economics. Discussion Paper Series 422.

Goklany IM (2009) Have increases in population, affluence and technology worsened human and environmental well-being? *Electronic Journal of Sustainable Development* 1(3).

Holdren JP (1991) Population and the energy problem. *Population and Environment* 12(3):231-255.

Holdren JP, Ehrlich PR (1974) Human population and the global environment. *American Scientist* 62:282-292.

Horvitz C, Schemske DW, Caswell H (1997) The relative "importance" of life-history stages to population growth: prospective and retrospective analyses. In S Tuljapurkar and H Caswell (Eds) *Structured-population Models in Marine, Terrestrial, and Freshwater Systems.* London, Chapman and Hall, Population and Community Biology Series 18: 247–271

Kim YJ, Strobino DM (1984) Decomposition of the difference between two rates with hierarchical effects. *Demography* 21(3):361-372.

Liddle B (2013) Population, affluence, and environmental impact across development: evidence from panel cointegration modeling. Available online at http://mpra.ub.uni-muenchen.de/52088. Retrieved 20 April 2018.

O'Neill BC, Chen BS (2002) Demographic determinants of household energy use in the United States. In W Lutz, A Praskavetz, WC Sanderson (Eds) *Population and Environment: Methods of Analysis.* New York, Population Council.

Poorter H, van der Werf A (1998) Is inherent variation in RGR determined by LAR at low irradience and by NAR at high irradience? A review of herbaceous species. In H Lambers, H Poorter, and MML Van Vuuren (Eds) *Inherent Variation in Plant Growth: Physiological Mechanisms and Ecological Consequences*. Leiden, Backhuys: 309–336.

Preston SH (1994) Population and environment: from Rio to Cairo. Liege, International Union for the Scientific Study of Population.

Ranjan A (2009) An empirical analysis of environmental impact of population affluence and technology. In S Somayaji and G Somayaji (Eds) *Environmental Concerns and Sustainable Development. Some Perspectives from India.* New Delhi, Tata Energy Resources Institute.

Rees M, Osborne CP, Woodward FI, Hulme SP, Turnbull LA, Taylor SH (2010) Partitioning the components of relative growth rate: how important is plant size variation? *The American Naturalist* 176(6). DOI: 10.1086/657037

Rees M, Grubb PJ, Kelly D (1996) Quantifying the impact of competition and spatial heterogeneity on the structure and dynamics of a four-species guild of winter annuals. *American Naturalist* 147(1):1–32.

Shi A (2001) Population growth and global carbon dioxide emission. Paper present at *IUSSP General Conference*, 18-24 August 2001, Salvador, Brazil. Session-S09. http://archive.iussp.org/Brazil2001/s00/S09_04_Shi.pdf. Retrieved: 10 May 2018

Shi (2003) The impact of population pressure on global carbon dioxide emissions, 1975-1996: evidence from global cross-country data. *Ecological Economics* 44(1):24-42.

United Nations (2000) *United Nations Millennium Declaration*. New York, United Nations. (A/Res/55/2).

United Nations (2015) *Transforming our World: The 2030 Agenda for Sustainable Development*. New York, United Nations.

United Nations (2017) *World Population Prospects: The 2017 Revision, Population Database*. Available at http://esa.un.org/unpp/, visited 20 April 2018.

United Nations Framework Convention for Climate Change (2009) *UNFCCC Resource Guide for Preparing the National Communications of Non-annex I Parties Module 3: National Greenhouse Gas Inventories*. Bonn, UNFCCC.

United Nations Population Fund (2014) *Programme of Action of the International Conference on Population Development. 20th Anniversary Edition*. New York, United Nations Population Fund.

World Bank (2007) *Growth and CO2 Emissions: How do Different Countries Fare?* Washington DC, The World Bank. Environment Department.

Wright IJ, Westoby M (2001) Understanding seedling growth relationships through specific leaf area and leaf nitrogen concentration: generalisations across growth forms and growth irradiance. *Oecologia* (Berlin) 127:21–29.

York R, Rosa EA, Dietz T (2003) STIRPAT, IPAT and ImPAT: analytical tools for unpacking the driving forces of environmental impacts. *Ecological Economics* 46(3):351-365.

Zhu Q, Peng X (2001) The impacts of population change on carbon emissions in China during 1978–2008. *Environmental Impact Assessment Review* 36:1-8.

Table 1

Energy use and CO_2 emissions in the world, 1990-2015

	World/Region	Energy use (Mtoe)				CO_2 emissions (Mt)			
		1990	2000	2010	2015	1990	2000	2010	2015
	World	8759	10020	12948	13769	20302	22672	29677	31452
	Regions								
	Africa	382	485	682	770	601	730	1062	1150
	Asia	2108	2889	4905	5565	4642	6766	12538	14431
	CIS	1373	898	1008	989	3639	2182	2366	2277
	Europe	1784	1854	1930	1808	4347	4205	4124	3760
	Latin America	463	598	783	857	883	1217	1568	1698
	Middle-East	223	372	648	775	598	985	1633	1962
	North America	2121	2523	2481	2477	5301	6215	5967	5752
	Pacific	103	129	151	152	290	371	429	422
	Countries								
1	Algeria	22	27	39	54	57	70	106	139
2	Argentina	46	62	79	89	104	141	183	201
3	Australia	87	108	128	127	260	337	392	383
4	Belgium	48	58	60	53	101	111	106	93
5	Brazil	141	188	266	298	191	293	369	450
6	Canada	211	254	265	274	428	527	546	570
7	Chile	14	25	31	37	30	53	73	84
8	China	870	1134	2615	3080	2201	3131	7594	8791
9	Colombia	24	26	31	35	48	55	66	74
10	Czech Republic	50	41	44	41	146	122	109	95
11	Egypt	32	41	73	76	82	98	180	179
12	France	225	255	261	246	347	374	348	299
13	Germany	355	337	327	308	957	821	766	737
14	India	306	441	693	845	513	898	1574	2011
15	Indonesia	99	156	213	212	151	281	410	450
16	Iran	69	123	204	243	190	324	514	601
17	Italy	151	172	174	152	386	424	394	331
18	Japan	439	518	499	434	974	1110	1071	1105
19	Kazakhstan	73	36	69	75	238	122	228	229
20	Kuwait	9	19	32	37	24	50	83	95
21	Malaysia	22	49	74	89	57	123	204	243
22	Mexico	123	150	175	186	279	370	441	446
23	Netherlands	66	76	83	73	157	185	194	173
24	New Zealand	13	17	19	21	26	30	30	32

World/Region	Energy use (Mtoe)				CO_2 emissions (Mt)			
	1990	2000	2010	2015	1990	2000	2010	2015
25 Nigeria	66	86	120	136	31	44	57	64
26 Norway	21	26	34	30	29	34	40	38
27 Poland	104	89	101	96	358	294	316	288
28 Portugal	17	25	23	22	38	60	49	49
29 Romania	62	36	35	32	162	86	74	70
30 Russia	882	619	688	690	2340	1514	1600	1557
31 Saudi Arabia	58	98	186	223	152	251	443	558
32 South Africa	92	109	142	143	303	342	442	449
33 South Korea	94	190	256	280	225	414	561	580
34 Spain	91	122	128	120	208	288	268	256
35 Sweden	46	46	51	47	48	42	48	39
36 Taiwan	48	85	111	109	110	215	266	259
37 Thailand	42	72	118	137	81	157	235	266
38 Turkey	52	76	107	130	129	199	267	318
39 Ukraine	243	130	132	91	618	281	263	180
40 United Arab Emirates	20	32	62	76	53	81	152	189
41 United Kingdom	206	223	203	181	558	539	488	404
42 United States	1910	2269	2216	2203	4873	5688	5421	5182
43 Uzbekistan	46	51	43	45	116	122	102	106
44 Venezuela	40	51	72	67	97	119	178	155
Rest of the countries	922	1001	1307	1454	1827	1852	2425	2633

Source: Enerdata (2017).

Table 2

Per capita energy use and Per capita CO_2 emissions in the world, regions and selected countries, 1990-2015

World/Region/ Country	Per capita energy use (Koe)				Per capita CO_2 emissions (Kg)			
	1990	2000	2010	2015	1990	2000	2010	2015
World	1649	1637	1816	1873	3822	3703	4282	4278
Regions								
Africa	609	599	658	653	959	903	1015	975
Asia	711	844	1283	1387	1566	1977	3280	3597
CIS	4901	3197	3578	3443	12990	7771	8397	7926
Europe	3186	3201	3189	2939	7761	7260	6814	6111
Latin America	1050	1150	1324	1368	2004	2339	2650	2710
Middle-East	1686	2216	3032	3272	4530	5868	7644	8283
North America	7569	8067	7237	6961	18917	19873	17407	16164
Pacific	3936	4261	4230	3944	11035	12274	12038	10966
Countries								
World								
1 Algeria	851	856	1092	1349	2206	2254	2923	3487
2 Argentina	1408	1662	1909	2049	3182	3799	4431	4624
3 Australia	5115	5681	5771	5324	15270	17669	17741	16104
4 Belgium	4777	5654	5517	4718	10067	10799	9691	8274
5 Brazil	941	1071	1354	1447	1279	1674	1875	2184
6 Canada	7616	8249	7753	7624	15458	17151	15993	15864
7 Chile	1058	1649	1816	2101	2299	3468	4293	4720
8 China	742	884	1923	2205	1877	2440	5585	6292
9 Colombia	707	639	680	728	1406	1359	1433	1528
10 Czech Republic	4791	3991	4213	3842	14117	11812	10345	8971
11 Egypt	562	581	863	809	1423	1401	2138	1906
12 France	3948	4280	4143	3820	6098	6268	5521	4634
13 Germany	4485	4131	4041	3771	12093	10073	9468	9017
14 India	351	419	563	646	590	852	1279	1537
15 Indonesia	544	736	876	820	831	1328	1690	1742
16 Iran	1233	1861	2740	3062	3376	4901	6889	7575
17 Italy	2648	3001	2915	2554	6765	7405	6598	5571
18 Japan	3522	4060	3879	3390	7826	8700	8329	8637
19 Kazakhstan	4441	2370	4215	4208	14366	8093	13888	12928
20 Kuwait	4341	9132	10700	9365	11585	24354	27687	24257
21 Malaysia	1209	2116	2642	2886	3146	5324	7273	7900
22 Mexico	1445	1478	1491	1475	3263	3638	3758	3541
23 Netherlands	4377	4778	5004	4300	10491	11610	11655	10215

World/Region/ Country		Per capita energy use (Koe)				Per capita CO_2 emissions (Kg)			
		1990	2000	2010	2015	1990	2000	2010	2015
24	New Zealand	3919	4464	4305	4498	7783	7797	6939	6986
25	Nigeria	697	703	756	752	323	357	363	351
26	Norway	4961	5815	6985	5720	6745	7467	8148	7326
27	Poland	2737	2315	2627	2497	9434	7638	8247	7531
28	Portugal	1731	2376	2205	2115	3837	5767	4582	4685
29	Romania	2651	1638	1717	1630	6893	3885	3633	3504
30	Russia	5977	4227	4805	4793	15856	10341	11179	10822
31	Saudi Arabia	3552	4713	6764	7082	9308	12107	16159	17680
32	South Africa	2440	2385	2749	2582	8072	7482	8569	8124
33	South Korea	2189	4011	5158	5533	5232	8729	11328	11471
34	Spain	2306	2993	2731	2589	5285	7046	5726	5518
35	Sweden	5409	5233	5416	4832	5655	4779	5132	4030
36	Taiwan	2351	3885	4825	4630	5393	9844	11493	11010
37	Thailand	741	1148	1754	1999	1440	2488	3497	3873
38	Turkey	972	1205	1475	1658	2389	3146	3685	4065
39	Ukraine	4717	2652	2889	2033	12013	5762	5744	4041
40	United Arab Emirates	10981	9993	7450	8271	28235	25717	18428	20631
41	United Kingdom	3600	3781	3200	2769	9752	9151	7706	6176
42	United States	7564	8047	7180	6886	19296	20170	17563	16197
43	Uzbekistan	2267	2048	1511	1450	5677	4922	3567	3412
44	Venezuela	1993	2094	2494	2148	4865	4854	6132	4970
Rest of the countries		769	675	727	734	1525	1248	1348	1330

Source: Enerdata (2017).

Table 3
Population and per capita real GDP (2005 US$ ppp) in the world, regions and selected countries, 1990-2015

World/Region/ Country		Population (Million)				GDP per capita (2005 US$ ppp)			
		1990	2000	2010	2015	1990	2000	2010	2015
World		5312	6123	6930	7352	7639	8897	11421	12780
Regions									
	Africa	627	809	1037	1180	3711	3497	4553	4677
	Asia	2965	3422	3822	4012	3079	4453	7403	9321
	CIS	280	281	282	287	10624	6513	11135	12046
	Europe	560	579	605	615	80704	95868	26730	111435
	Latin America	441	520	592	627	8518	9662	11758	12401
	Middle-East	132	168	214	237	13808	15872	19949	20233
	North America	280	313	343	356	32528	40432	43132	47251
	Pacific	26	30	36	38	18715	22104	25260	26779
Countries									
1	Algeria	26	31	36	40	9161	8996	12474	12232
2	Argentina	33	37	41	43	9581	13198	18235	19003
3	Australia	17	19	22	24	23998	29697	34646	36654
4	Belgium	10	10	11	11	25343	30780	33490	34431
5	Brazil	149	175	197	206	9186	10098	12863	12988
6	Canada	28	31	34	36	27927	33358	36232	38173
7	Chile	13	15	17	18	6899	11128	15274	16910
8	China	1172	1283	1360	1397	1307	3223	8335	11711
9	Colombia	34	40	46	48	6708	7398	10596	11590
10	Czech Rep.	10	10	11	11	17277	18244	24204	25932
11	Egypt	57	70	84	94	5260	6577	8664	8906
12	France	57	60	63	64	25228	29659	31566	32310
13	Germany	79	81	81	82	26813	31661	35217	37175
14	India	870	1053	1231	1309	1580	2246	3986	5154
15	Indonesia	181	212	243	258	3987	5169	7753	9228
16	Iran	56	66	75	79	9049	10555	15643	14527
17	Italy	57	57	60	60	24390	28645	28233	27417
18	Japan	125	128	129	128	26314	28739	30624	31945
19	Kazakhstan	17	15	16	18	11202	8542	18151	20278
20	Kuwait	2	2	3	4	40860	62256	70924	60005
21	Malaysia	18	23	28	31	9395	14522	19945	22250
22	Mexico	85	102	117	126	10063	12007	12423	13299
23	Netherlands	15	16	17	17	27491	35774	39741	39469

World/Region/ Country		Population (Million)				GDP per capita (2005 US$ ppp)			
		1990	2000	2010	2015	1990	2000	2010	2015
24	New Zealand	3	4	4	5	19064	22640	24939	27593
25	Nigeria	95	122	159	181	4291	4018	7414	8001
26	Norway	4	4	5	5	32888	44566	49175	48860
27	Poland	38	39	38	38	8275	11809	17115	20056
28	Portugal	10	10	11	10	16789	21444	23009	21879
29	Romania	23	22	20	20	7408	6973	11564	13314
30	Russia	148	146	143	144	12688	8607	14159	14857
31	Saudi Arabia	16	21	27	32	31536	32420	41342	44749
32	South Africa	38	46	52	55	8648	8505	11429	10963
33	South Korea	43	47	50	51	11447	19526	28123	32612
34	Spain	39	41	47	46	19900	25175	27712	27411
35	Sweden	9	9	9	10	25734	30658	37013	37955
36	Taiwan	20	22	23	23	8079	14005	18895	20992
37	Thailand	57	63	67	69	5922	8182	12100	13557
38	Turkey	54	63	72	78	8120	9888	12568	14465
39	Ukraine	51	49	46	45	9418	4312	6722	6352
40	United Arab Emirates	2	3	8	9	99296	92285	51606	59322
41	United Kingdom	57	59	63	65	24457	30879	34004	36178
42	United States	253	282	309	320	32620	40972	43895	47450
43	Uzbekistan	20	25	29	31	2705	2183	3835	5077
44	Venezuela	20	24	29	31	12867	12833	15249	13780
Rest of the world		1198	1483	1798	1980	4066	4319	5440	6035

Source: United Nations (2017), Enerdata (2017).

Table 4

Energy intensity of GDP and CO_2 intensity of GDP in the world, regions and selected countries, 1990-2015

World/Region/ Country	Energy intensity (Koe per 2005 US$ ppp)				CO_2 intensity (KCO_2 per 2005 US$ ppp)			
	1990	2000	2010	2015	1990	2010	2000	2015
World	0.219	0.186	0.159	0.147	0.500	0.375	0.416	0.335
Regions								
Africa	0.185	0.185	0.151	0.143	0.258	0.223	0.258	0.208
Asia	0.229	0.191	0.175	0.149	0.509	0.443	0.444	0.386
CIS	0.482	0.494	0.323	0.291	1.223	0.754	1.193	0.658
Europe	0.162	0.136	0.120	0.105	0.396	0.255	0.308	0.219
Latin America	0.129	0.121	0.115	0.111	0.235	0.225	0.242	0.219
Middle-East	0.125	0.144	0.159	0.162	0.328	0.383	0.370	0.409
North America	0.235	0.201	0.167	0.150	0.582	0.347	0.492	0.342
Pacific	0.213	0.192	0.168	0.148	0.590	0.477	0.555	0.409
Countries								
1 Algeria	0.093	0.095	0.095	0.110	0.219	0.234	0.225	0.268
2 Argentina	0.147	0.126	0.110	0.108	0.320	0.243	0.283	0.245
3 Australia	0.213	0.191	0.167	0.145	0.637	0.512	0.594	0.437
4 Belgium	0.188	0.184	0.163	0.137	0.409	0.289	0.360	0.243
5 Brazil	0.102	0.106	0.105	0.111	0.134	0.146	0.165	0.171
6 Canada	0.273	0.247	0.214	0.200	0.553	0.441	0.516	0.405
7 Chile	0.153	0.148	0.125	0.124	0.334	0.281	0.308	0.262
8 China	0.568	0.274	0.233	0.188	1.440	0.670	0.745	0.536
9 Colombia	0.105	0.086	0.070	0.063	0.198	0.135	0.183	0.126
10 Czech Rep.	0.277	0.219	0.173	0.148	0.838	0.427	0.654	0.352
11 Egypt	0.107	0.088	0.098	0.091	0.256	0.247	0.218	0.215
12 France	0.156	0.144	0.131	0.118	0.246	0.175	0.213	0.145
13 Germany	0.167	0.130	0.116	0.101	0.443	0.269	0.317	0.241
14 India	0.222	0.186	0.142	0.125	0.374	0.321	0.380	0.305
15 Indonesia	0.136	0.142	0.117	0.089	0.203	0.218	0.249	0.194
16 Iran	0.136	0.176	0.176	0.211	0.353	0.440	0.454	0.520
17 Italy	0.109	0.105	0.103	0.093	0.283	0.234	0.260	0.204
18 Japan	0.134	0.141	0.126	0.106	0.308	0.272	0.305	0.270
19 Kazakhstan	0.396	0.277	0.243	0.207	1.254	0.765	0.938	0.602
20 Kuwait	0.106	0.147	0.160	0.156	0.326	0.390	0.367	0.401
21 Malaysia	0.129	0.146	0.141	0.130	0.294	0.365	0.348	0.324
22 Mexico	0.144	0.123	0.120	0.111	0.304	0.303	0.296	0.262
23 Netherlands	0.159	0.134	0.129	0.109	0.376	0.293	0.321	0.261

World/Region/ Country	Energy intensity (Koe per 2005 US$ ppp)				CO$_2$ intensity (KCO$_2$ per 2005 US$ ppp)			
	1990	2000	2010	2015	1990	2010	2000	2015
24 New Zealand	0.206	0.197	0.168	0.163	0.349	0.278	0.355	0.264
25 Nigeria	0.163	0.175	0.104	0.094	0.069	0.049	0.089	0.043
26 Norway	0.151	0.130	0.146	0.117	0.198	0.166	0.164	0.134
27 Poland	0.331	0.196	0.152	0.125	1.167	0.482	0.647	0.370
28 Portugal	0.103	0.111	0.098	0.097	0.235	0.199	0.265	0.211
29 Romania	0.358	0.235	0.149	0.122	0.927	0.314	0.558	0.267
30 Russia	0.471	0.491	0.341	0.323	1.159	0.790	1.193	0.717
31 Saudi Arabia	0.113	0.145	0.168	0.158	0.301	0.391	0.361	0.394
32 South Africa	0.282	0.280	0.259	0.236	0.765	0.750	0.759	0.714
33 South Korea	0.191	0.205	0.179	0.170	0.473	0.403	0.456	0.364
34 Spain	0.116	0.119	0.100	0.094	0.263	0.207	0.277	0.200
35 Sweden	0.210	0.171	0.152	0.127	0.234	0.139	0.182	0.101
36 Taiwan	0.291	0.277	0.256	0.221	0.690	0.608	0.703	0.516
37 Thailand	0.125	0.140	0.146	0.147	0.239	0.289	0.301	0.281
38 Turkey	0.120	0.122	0.117	0.115	0.297	0.293	0.324	0.292
39 Ukraine	0.501	0.615	0.413	0.320	1.341	0.855	1.371	0.652
40 United Arab Emirates	0.111	0.108	0.145	0.139	0.281	0.357	0.274	0.421
41 United Kingdom	0.147	0.122	0.095	0.077	0.393	0.227	0.291	0.167
42 United States	0.232	0.196	0.163	0.145	0.584	0.400	0.489	0.336
43 Uzbekistan	0.838	0.938	0.406	0.286	2.086	0.930	2.146	0.651
44 Venezuela	0.155	0.163	0.169	0.156	0.366	0.402	0.371	0.350
Rest of the world	0.189	0.156	0.134	0.122	0.375	0.248	0.289	0.220

Source: Enerdata (2017).

Table 5

Multipliers of energy use (m_E), population (m_P), per capita real GDP (m_I), energy intensity of GDP (m_U), carbon intensity of energy use (m_T) and CO2 emissions (m_C) in the world and its different geo-political regions and selected countries, 1990-2015

World/Regions	Average annual rate of change in					
	m_E	m_P	m_I	m_U	m_T	m_C
World	1.565	1.384	1.673	0.676	0.990	1.549
Regions						
Africa	2.016	1.880	1.260	0.772	0.948	1.912
Asia	2.640	1.353	3.028	0.649	1.178	3.109
CIS	0.720	1.026	1.134	0.604	0.868	0.626
Europe	1.013	1.098	1.425	0.650	0.854	0.865
Latin America	1.853	1.422	1.456	0.863	1.037	1.922
Middle-East	3.481	1.794	1.465	1.300	0.942	3.281
North America	1.168	1.270	1.453	0.636	0.929	1.085
Pacific	1.468	1.465	1.431	0.693	0.992	1.456
Countries						
1 Algeria	2.439	1.539	1.289	1.230	0.997	2.432
2 Argentina	1.930	1.327	1.899	0.766	0.999	1.928
3 Australia	1.454	1.397	1.536	0.678	1.013	1.473
4 Belgium	1.114	1.128	1.380	0.716	0.832	0.927
5 Brazil	2.120	1.379	1.341	1.146	1.111	2.354
6 Canada	1.300	1.298	1.402	0.714	1.025	1.332
7 Chile	2.663	1.341	2.615	0.759	1.034	2.754
8 China	3.538	1.192	9.002	0.330	1.129	3.995
9 Colombia	1.449	1.407	1.709	0.603	1.055	1.530
10 Czech Rep.	0.822	1.025	1.514	0.530	0.792	0.652
11 Egypt	2.352	1.633	1.598	0.901	0.931	2.189
12 France	1.095	1.132	1.286	0.752	0.786	0.860
13 Germany	0.868	1.033	1.369	0.614	0.887	0.770
14 India	2.765	1.504	3.202	0.574	1.418	3.920
15 Indonesia	2.146	1.423	2.199	0.686	1.389	2.981
16 Iran	3.505	1.411	1.525	1.629	0.904	3.167
17 Italy	1.005	1.042	1.144	0.843	0.854	0.858
18 Japan	0.989	1.028	1.257	0.766	1.147	1.134
19 Kazakhstan	1.017	1.073	1.874	0.506	0.950	0.966
20 Kuwait	4.044	1.875	1.702	1.268	0.971	3.925
21 Malaysia	4.065	1.703	2.274	1.049	1.052	4.277
22 Mexico	1.505	1.475	1.257	0.812	1.063	1.600
23 Netherlands	1.112	1.132	1.405	0.699	0.991	1.102

World/Regions	Average annual rate of change in					
	m_E	m_P	m_I	m_U	m_T	m_C
24 New Zealand	1.559	1.358	1.186	0.968	0.782	1.219
25 Nigeria	2.050	1.902	1.736	0.621	1.009	2.069
26 Norway	1.412	1.224	1.603	0.720	0.942	1.330
27 Poland	0.920	1.008	2.518	0.362	0.875	0.805
28 Portugal	1.279	1.047	1.362	0.898	0.999	1.278
29 Romania	0.520	0.846	1.765	0.348	0.826	0.430
30 Russia	0.782	0.975	1.103	0.727	0.851	0.666
31 Saudi Arabia	3.853	1.933	1.453	1.372	0.953	3.671
32 South Africa	1.558	1.472	1.079	0.981	0.951	1.482
33 South Korea	2.979	1.179	2.851	0.886	0.867	2.584
34 Spain	1.325	1.180	1.372	0.818	0.930	1.232
35 Sweden	1.018	1.140	1.660	0.538	0.798	0.812
36 Taiwan	2.277	1.156	2.729	0.722	1.037	2.361
37 Thailand	3.271	1.213	2.290	1.177	0.998	3.264
38 Turkey	2.476	1.452	1.731	0.985	0.998	2.470
39 Ukraine	0.374	0.868	0.692	0.623	0.781	0.292
40 United Arab Emirates	3.707	4.921	0.488	1.545	0.970	3.596
41 United Kingdom	0.880	1.144	1.489	0.517	0.823	0.724
42 United States	1.153	1.267	1.458	0.625	0.922	1.063
43 Uzbekistan	0.968	1.514	1.926	0.332	0.939	0.910
44 Venezuela	1.690	1.569	1.067	1.010	0.948	1.602
Rest of the countries	1.577	1.653	1.478	0.646	0.914	1.441

Source: Author's calculations

Table 6

Average annual rate of change in energy use, population, per capita real GDP, energy intensity of GDP, carbon intensity of energy use and CO2 emissions in the world and its different geo-political regions, 1990-2015

World/Regions	Average annual rate of change in					
	E	*P*	*I*	*U*	*T*	*C*
World	1.792	1.300	2.059	-1.567	-0.041	1.751
Regions						
Africa	2.805	2.525	0.925	-1.037	-0.212	2.592
Asia	3.883	1.210	4.431	-1.732	0.654	4.537
CIS	-1.311	0.101	0.502	-2.017	-0.564	-1.875
Europe	0.053	0.375	1.416	-1.725	-0.634	-0.581
Latin America	2.467	1.407	1.502	-0.588	0.147	2.614
Middle-East	4.990	2.338	1.528	1.050	-0.237	4.752
North America	0.621	0.956	1.493	-1.812	-0.294	0.327
Pacific	1.537	1.528	1.433	-1.469	-0.034	1.503
Countries						
1 Algeria	3.566	1.724	1.015	0.827	-0.011	3.554
2 Argentina	2.631	1.130	2.565	-1.065	-0.005	2.626
3 Australia	1.497	1.336	1.717	-1.556	0.052	1.549
4 Belgium	0.433	0.482	1.290	-1.339	-0.735	-0.303
5 Brazil	3.005	1.286	1.175	0.545	0.420	3.425
6 Canada	1.048	1.044	1.351	-1.346	0.099	1.147
7 Chile	3.918	1.175	3.844	-1.101	0.134	4.052
8 China	5.055	0.701	8.790	-4.436	0.485	5.540
9 Colombia	1.485	1.367	2.143	-2.025	0.216	1.700
10 Czech Rep.	-0.782	0.100	1.660	-2.542	-0.931	-1.713
11 Egypt	3.421	1.963	1.875	-0.416	-0.288	3.133
12 France	0.362	0.495	1.007	-1.139	-0.966	-0.603
13 Germany	-0.565	0.129	1.257	-1.951	-0.480	-1.045
14 India	4.069	1.634	4.655	-2.220	1.396	5.464
15 Indonesia	3.054	1.411	3.151	-1.508	1.315	4.369
16 Iran	5.017	1.378	1.687	1.952	-0.406	4.611
17 Italy	0.018	0.163	0.537	-0.682	-0.632	-0.614
18 Japan	-0.044	0.110	0.915	-1.068	0.548	0.504
19 Kazakhstan	0.066	0.282	2.512	-2.728	-0.206	-0.140
20 Kuwait	5.589	2.513	2.126	0.949	-0.119	5.470
21 Malaysia	5.610	2.130	3.287	0.193	0.203	5.813
22 Mexico	1.636	1.554	0.916	-0.834	0.245	1.881
23 Netherlands	0.424	0.495	1.361	-1.433	-0.035	0.389

World/Regions		Average annual rate of change in					
		E	*P*	*I*	*U*	*T*	*C*
24	New Zealand	1.775	1.224	0.683	-0.132	-0.983	0.792
25	Nigeria	2.872	2.571	2.206	-1.905	0.037	2.909
26	Norway	1.379	0.809	1.886	-1.317	-0.239	1.140
27	Poland	-0.334	0.033	3.693	-4.060	-0.534	-0.869
28	Portugal	0.985	0.183	1.235	-0.432	-0.003	0.982
29	Romania	-2.612	-0.668	2.274	-4.218	-0.763	-3.375
30	Russia	-0.984	-0.101	0.391	-1.273	-0.645	-1.629
31	Saudi Arabia	5.395	2.636	1.496	1.264	-0.193	5.202
32	South Africa	1.773	1.547	0.303	-0.077	-0.200	1.572
33	South Korea	4.366	0.658	4.191	-0.482	-0.569	3.798
34	Spain	1.126	0.663	1.266	-0.803	-0.290	0.836
35	Sweden	0.072	0.523	2.026	-2.477	-0.904	-0.832
36	Taiwan	3.292	0.581	4.016	-1.305	0.144	3.436
37	Thailand	4.740	0.774	3.314	0.652	-0.008	4.732
38	Turkey	3.627	1.491	2.196	-0.060	-0.009	3.617
39	Ukraine	-3.935	-0.567	-1.474	-1.894	-0.990	-4.925
40	United Arab Emirates	5.241	6.374	-2.873	1.740	-0.121	5.119
41	United Kingdom	-0.513	0.537	1.592	-2.642	-0.777	-1.290
42	United States	0.571	0.946	1.508	-1.883	-0.325	0.246
43	Uzbekistan	-0.129	1.658	2.621	-4.408	-0.250	-0.379
44	Venezuela	2.099	1.801	0.259	0.039	-0.213	1.886
Rest of the countries		1.822	2.009	1.562	-1.749	-0.360	1.462

Source: Author’s calculations

Table 7

Decomposition of the inter-country variance in the rate of change in energy use and CO_2 emissions, 1990-2015

Particulars	Variance and covariance		Variance explained		Importance
			Total	Per cent	
			Energy use		
Var (*E*)			5.081	100.00	100.00
Var(*E*) explained by *P*	Var (*P*)	1.253	1.691	33.27	22.65
	Cov (*PI*)	-0.449			
	Cov (*PU*)	0.887			
Var(*E*) explained by *I*	Var (*I*)	2.975	1.387	27.30	39.91
	Cov (*IP*)	-0.449			
	Cov (*IU*)	-1.138			
Var(*E*) explained by *U*	Var (*U*)	2.225	2.004	39.43	37.44
	Cov (*UP*)	0.887			
	Cov (*UI*)	-1.138			
			CO_2 emissions		
Var (*C*)			6.557	100.00	100.00
Var(*C*) explained by *P*	Var (*P*)	1.253	1.870	28.52	21.45
	Cov (*PI*)	-0.449			
	Cov (*PU*)	0.887			
	Cov (*PT*)	0.179			
Var(*C*) explained by *I*	Var (*I*)	2.975	1.747	26.64	38.13
	Cov (*IP*)	-0.449			
	Cov (*IU*)	-1.138			
	Cov (*IT*)	0.359			
Var(*C*) explained by *U*	Var (*U*)	2.225	2.037	31.51	33.65
	Cov (*UP*)	0.887			
	Cov (*UI*)	-1.138			
	Cov (*UT*)	0.063			
Var(*C*) explained by *T*	Var (*T*)	0.273	0.874	13.33	6.77
	Cov (*TP*)	0.179			
	Cov (*TI*)	0.359			
	Cov (*TU*)	0.063			

Source: Author's calculations

Table 8

Decomposition of the absolute change in Energy use ∇E and CO_2 emissions in the world and its geo-political regions, 1990-2015

Change	World	Africa	Asia	CIS	Europe	Latin America	Middle East	North America	Pacific
					Energy use				
∇E	4837	388	3457	-384	24	395	552	356	48
d_P	3286	336	745	35	176	195	177	573	48
d_I	5752	99	4275	184	758	211	104	960	45
d_U	-2770	-57	-750	-522	-629	-48	72	-778	-31
d_{PI}	2209	87	1510	5	75	89	82	259	21
d_{PU}	-1064	-50	-265	-13	-62	-20	57	-210	-14
d_{IU}	-1862	-15	-1520	-70	-267	-22	34	-352	-13
d_{PIU}	-715	-13	-537	-2	-26	-9	27	-95	-6
	3620	350	1189	30	174	227	256	566	50
	5687	131	4091	151	653	242	171	882	47
	-4471	-94	-1822	-564	-802	-72	127	-1091	-47
OR	0.570	0.258	0.471	2.718	0.976	0.203	0.000	0.801	0.573
					CO_2 emissions				
∇C	11150	548	9789	-1362	-587	815	1364	451	132
g_P	7797	529	1639	93	428	372	475	1431	135
g_I	13647	156	9412	487	1847	403	278	2399	125
g_U	-6572	-90	-1651	-1384	-1532	-92	194	-1945	-87
g_T	-208	-31	825	-479	-637	33	-34	-376	-2
g_{PI}	5241	138	3324	12	182	170	221	648	58
g_{PU}	-2524	-79	-583	-35	-151	-39	154	-525	-40
g_{PT}	-80	-27	291	-12	-63	14	-27	-101	-1
g_{IU}	-4418	-23	-3347	-185	-651	-42	90	-880	-37
g_{IT}	-140	-8	1673	-64	-271	15	-16	-170	-1
g_{UT}	67	5	-293	182	224	-3	-11	138	1
g_{PIU}	-1697	-21	-1182	-5	-64	-18	72	-238	-17
g_{PIT}	-54	-7	591	-2	-27	6	-13	-46	0
g_{PUT}	26	4	-104	5	22	-1	-9	37	0
g_{IUT}	45	1	-595	24	95	-2	-5	62	0
g_{PIUT}	17	1	-210	1	9	-1	-4	17	0
OR	0.442	0.224	0.297	4.260	1.376	0.122	0.045	0.844	0.448

Source: Author's calculations

Table 9

Increase in energy use and CO2 emissions in different countries, 1990-2015

Country		Increase in energy use (Mtoe)		Increase in CO$_2$ emissions (Mt)		Offset ratio (OR)	
		Total	Per cent	Total	Per cent	Energy use	CO$_2$ emissions
World		4837	100.0	11150	100.0	0.570	0.442
1	Algeria	32	0.7	82	0.7	0.000	0.003
2	Argentina	43	0.9	97	0.9	0.388	0.263
3	Australia	40	0.8	123	1.1	0.604	0.458
4	Belgium	5	0.1	-7	-0.1	0.795	1.205
5	Brazil	157	3.2	259	2.3	0.000	0.000
6	Canada	63	1.3	142	1.3	0.635	0.484
7	Chile	23	0.5	53	0.5	0.337	0.211
8	China	2209	45.7	6590	59.1	0.739	0.576
9	Colombia	11	0.2	26	0.2	0.680	0.515
10	Czech Rep.	-9	-0.2	-51	-0.5	1.321	1.962
11	Egypt	44	0.9	97	0.9	0.160	0.168
12	France	21	0.4	-49	-0.4	0.792	1.473
13	Germany	-47	-1.0	-220	-2.0	1.318	1.872
14	India	540	11.2	1498	13.4	0.537	0.333
15	Indonesia	113	2.3	299	2.7	0.462	0.264
16	Iran	174	3.6	411	3.7	0.000	0.077
17	Italy	1	0.0	-55	-0.5	0.976	2.117
18	Japan	-5	-0.1	131	1.2	1.037	0.612
19	Kazakhstan	1	0.0	-8	-0.1	0.984	1.057
20	Kuwait	28	0.6	71	0.6	0.000	0.021
21	Malaysia	67	1.4	186	1.7	0.000	0.000
22	Mexico	62	1.3	167	1.5	0.408	0.264
23	Netherlands	7	0.1	16	0.1	0.811	0.744
24	New Zealand	7	0.1	6	0.1	0.085	0.522
25	Nigeria	70	1.4	33	0.3	0.544	0.389
26	Norway	9	0.2	9	0.1	0.572	0.534
27	Poland	-8	-0.2	-70	-0.6	1.052	1.214
28	Portugal	5	0.1	11	0.1	0.343	0.246
29	Romania	-30	-0.6	-92	-0.8	1.509	2.044
30	Russia	-192	-4.0	-783	-7.0	2.981	5.175
31	Saudi Arabia	165	3.4	406	3.6	0.000	0.035
32	South Africa	51	1.1	146	1.3	0.051	0.118
33	South Korea	186	3.8	356	3.2	0.162	0.216
34	Spain	29	0.6	48	0.4	0.475	0.507
35	Sweden	1	0.0	-9	-0.1	0.980	1.335

Country		Increase in energy use (Mtoe)		Increase in CO_2 emissions (Mt)		Offset ratio (OR)	
		Total	Per cent	Total	Per cent	Energy use	CO_2 emissions
36	Taiwan	61	1.3	149	1.3	0.408	0.267
37	Thailand	95	2.0	184	1.7	0.000	0.002
38	Turkey	77	1.6	189	1.7	0.025	0.016
39	Ukraine	-152	-3.1	-438	-3.9	4.026	6.454
40	United Arab Emirates	55	1.1	136	1.2	0.590	0.443
41	United Kingdom	-25	-0.5	-154	-1.4	1.171	1.621
42	United States	293	6.1	309	2.8	0.819	0.882
43	Uzbekistan	-1	0.0	-10	-0.1	1.017	1.084
44	Venezuela	27	0.6	58	0.5	0.000	0.080
Rest of the countries		534	11.0	808	7.2	0.600	0.570

Source: Author's calculations

Figure 1

Trends in energy use (Mtoe) in the world, 1990-2015

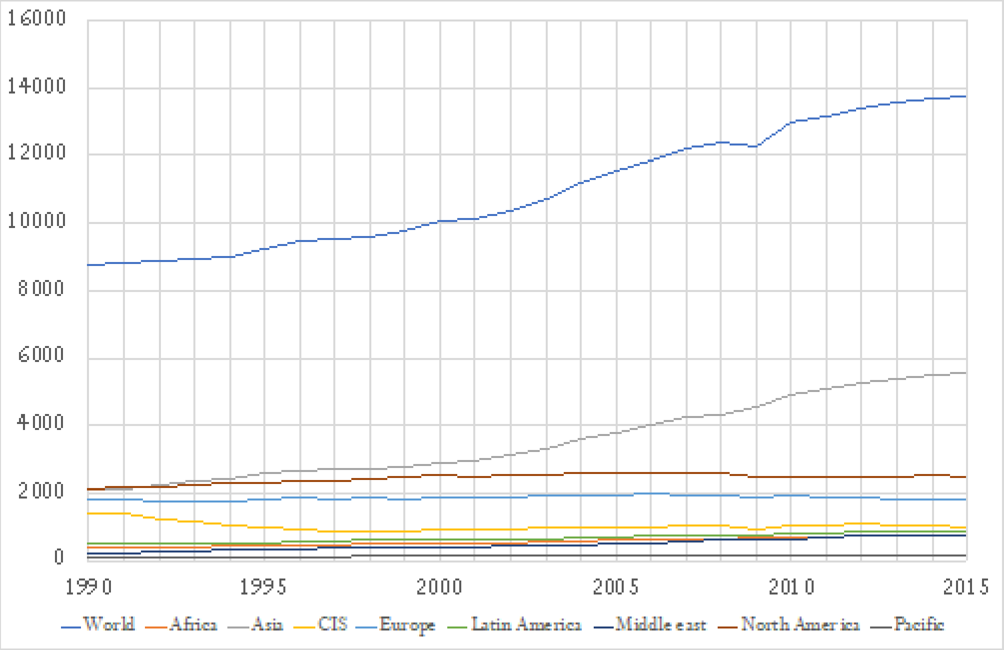

Figure 2
Trends in CO2 emissions in the world, 1990-2015