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Author(s): Aalok Ranjan Chaurasia

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Population effects of increase in world energy use and CO$_2$ emissions: 1990–2019

Aalok Ranjan Chaurasia$^1$

MLC Foundation and ‘Shyam’ Institute, Bhopal, MP, India

Abstract

This paper analyses population effects of increase in world energy use and CO$_2$ emissions between 1990–2019 following a decomposition framework with interaction effects. The analysis has also been carried out for the 44 countries which accounted for most of the increase in world energy use and CO$_2$ emissions during 1990–2019. Population growth was found to have a significant effect on both the increase in energy use and CO$_2$ emissions at the global level, although the contribution of population growth to these increases has varied widely across countries. There is a need for integrating population factors in the sustainable development processes, particularly efforts directed towards environmental sustainability.

Keywords: population; energy use; global CO$_2$ emissions.

Introduction

The impact of human activity on the environment can be conceptualised in terms of the use of natural resources and resulting wastes generated. The environment provides natural resources necessary for human activity. It also serves as the repository of wastes generated as a result of natural resource use. The quantum

$^1$ aalok@mlcfoundation.org.in
arajan@shyaminstitute.in
of natural resource use is determined by the extensiveness and intensity of natural resource use while the extent of wastes generated is determined by the efficiency of natural resource use, in addition to the extensiveness and intensity of natural resource use. The relationship between extensiveness, intensity and efficiency in deciding the quantum of natural resource use and extent of wastes generated is multiplicative, not additive. Implications of human activity on the environment, therefore, should be analysed in terms of extensiveness, intensity and efficiency of natural resource use. Such an analysis requires quantifying natural resource use and measuring its extensiveness, intensity and efficiency. Extensiveness of natural resource use can be measured in terms of the number of human beings or population size. Other things being equal, the larger the population the more the natural resource use. Intensity, on the other hand, can be measured in terms of per capita natural resource consumption. Finally, efficiency can be measured in terms of wastes generated per unit of natural resources used. Population, in this conceptualization, is an integral component of any analysis of the environmental impact of human activity. However, there is a conspicuous silence in recent years about the role of population in the debate on environmental sustainability. For example, the United Nations 2030 Agenda for Sustainable Development pays only a passing attention to population related issues and concerns in the quest to secure environmental sustainability (United Nations, 2015). Kopnina and Washington (2016) have discussed at length why population growth has been ignored in setting priorities for environmental sustainability. They conclude that without giving due attention to the population dimension of environmental sustainability, the probability of securing an ecologically sustainable future will be vanishingly small.

Concern about the implications of size and growth of population on the use of natural resources is not new and dates back to time immemorial. In ancient times, Chinese philosophers attempted to formulate an ideal proportion between land and population to ensure survival of mankind and for the development and well-being of society. The question of ‘optimum population’ in the context of ideal conditions for the development of the full potential of an individual was also discussed by Greek Philosophers Plato and Aristotle. Similar echoes may also be found in Arthashastra written by Kautilya in India (United Nations, 1973). During the Medieval period, availability of natural resources necessary for sustaining life was argued to be a key factor in population growth (Batero, 1589). The view
prevailing at that time was that ‘resources’ determined population’. More than two centuries later, Malthus was the first to argue that misery and vice would result from the differential pace of growth between population and the productivity of agriculture necessary to support it (Malthus, 1960 [1798]). In the 1940s the concern about population growth shifted to natural resources, particularly energy supplies, whereas in 1950s, especially in the less developed countries, this concern revolved around physical capital (Preston, 1994). The negative effects of population growth on the environment have also been highlighted in a number of studies carried out in 1960s and 1970s (Ehrlich, 1968; Forrester, 1971; Meadows et al, 1972). In recent years, concern about the environmental impact of population growth has focused on the wastes generated as a result of natural resource use. It is argued that excessive use of natural resources is causing irreparable damage to the environment with emissions of greenhouse gases such as carbon dioxide ($\text{CO}_2$) being the most glaring example of the irrational use of natural resources (Chaurasia [Ranjan], 2009).

Ehrlich (1968) was the first to propose a simple analytical framework, known as IPAT (Impact = Population x Affluence x Technology) framework, for an ex post analysis of the environmental impact of human activity. This framework describes how natural resource use can be explained in terms of extensiveness (population size), intensity (per capita natural resource use) and efficiency (wastes generated per unit of natural resource use). This simple yet straightforward analytical framework has been criticized for a number of perceived flaws (O’Neil and Chen, 2002), but it has almost become the norm in analysing population effects of the environment. The framework illustrates the multiplicative nature of relationship among driving factors of natural resource use as each factor amplifies changes in other factors. A small change in population induces a small absolute impact on natural resources use in a country with low-income and low intensity of natural resources use but much greater effect in a high-income country where intensity of natural resources use is high (O’Neil and Chen, 2002).

There have been efforts to improve the simple IPAT framework. Notable among these efforts is the stochastic version of the framework known as STIRPAT framework (Dietz and Rosa, 1994; Dietz, Rosa and York, 2007; Chertow, 2001). Another framework is the ImPACT framework which divides the affluence component of the IPAT framework into two components separating energy
use per capita from income per capita (Waggoner and Ausubel, 2002). In this framework, which is based on the Kaya identity (Kaya, 1990), population, per capita income, natural resource use per capita and waste generated per unit of natural resource use determine the impact of human activity on the environment. I have previously used this framework to analyse the change in natural resource use and waste generated in the world during 1990–2000 and found that although the main driver of the environmental impact of human activity was the increase in per capita income or affluence, the effect of population growth on the environment was quite substantial. The debate about the environmental impact of population growth, however, remains inconclusive. Different perspectives on the effect of population size on the environment have been discussed by Weber and Sciubba (2019) who have argued that one reason for the prevailing inconclusiveness is the approach of these analyses. Most of the population-environment impact analyses are based on cross-country data which suffer from high level of dissimilarity and strong collinearity among factors that influence both increase in natural resource use and resulting wastes generated. Onanuga (2017) has analysed population elasticity of CO$_2$ emissions in 26 African countries on the basis of time series data for the period 1971–2013 and observed that the response of emissions to population growth has a limiting effect in some countries but a contributory effect in others. Shi (2003) found a direct relationship between population change and CO$_2$ emissions in 93 countries during 1975–1996. A similar result has also been obtained by Cole and Neumayer (2004).

In this paper, I carry out an ex post analysis of the contribution of population change to the change in energy use and CO$_2$ emissions in the world and in its 44 countries during 1990–2019. The 44 countries included in the present analysis account for nearly all the increase in world energy use and CO$_2$ emissions. The paper also carries out country-specific analyses to highlight population effect of the environment as reflected through the increase in energy use and CO$_2$ emissions. The paper separates the direct effect of population change from its indirect effect that works through the change in the intensity and efficiency of natural resources use. The findings of the analysis emphasise the need for population factors to be integrated in efforts directed towards securing environmental sustainability.

The paper is organised as follows. The next section of the paper outlines the methodology. I use a decomposition framework with interaction effects to
estimate the contribution of organized population change to the change in energy use and CO₂ emissions. Section three describes the data source. The analysis is based on the data made available by EnerData, an independent research and consulting firm. Section four presents a snapshot of the trend in energy use and CO₂ emissions along with the trend in population, consumption and technology. Results of the decomposition analysis are presented in section five. The last section discusses policy implications in the context of sustainable development.

Analytical framework
Let $E$ denote the total energy use and $P$ denote population size. Then, total energy use may be written as at product of population size and per capita energy use

$$E = P \cdot \left( \frac{E}{P} \right)$$

(1)

It is well-known that there is a linear relationship between per capita income and per capita energy use (Cole et al, 1997; Suri and Chapman, 1998). If $G$ denotes the real gross domestic product (GDP), then equation (1) may be extended as

$$E = P \cdot \left( \frac{G}{P} \right) \cdot \left( \frac{E}{G} \right) = P \cdot A \cdot U$$

(2)

where $A = G/P$ is the per capita real GDP which is a commonly used indicator of per capita income and the ratio $U = (E/P)/(G/P) = (E/G)$ is the ratio of per capita energy use to per capita real GDP. It is known as the energy intensity of GDP.

Extending the above arguments further, total CO₂ emissions, as a result of energy use may be written as

$$C = E \cdot \left( \frac{C}{E} \right) = P \cdot \left( \frac{E}{P} \right) \cdot \left( \frac{C}{E} \right) = P \cdot \left( \frac{G}{P} \right) \cdot \left( \frac{E/G}{P} \right) \cdot \left( \frac{C/E}{G/P} \right) = P \cdot A \cdot U \cdot T$$

(3)

where $T = (C/P)/(E/P) = (C/E)$ is CO₂ emissions per unit energy use and is termed as carbon intensity of energy use. The change in energy use and CO₂ emissions between two points in time $t_2 \succ t_1$ can be captured in relative terms and in absolute terms. In relative terms, the change in energy use and CO₂ emissions can be written as

$$r_E = \left( \frac{E_2}{E_1} \right) = \left( \frac{P_2}{P_1} \right) \cdot \left( \frac{A_2}{A_1} \right) \cdot \left( \frac{U_2}{U_1} \right) = r_P \cdot r_A \cdot r_U$$

(4)
\[ r_c = \left( \frac{C_2}{C_1} \right) = \left( \frac{P_2}{P_1} \right) \times \left( \frac{A_2}{A_1} \right) \times \left( \frac{U_2}{U_1} \right) \times \left( \frac{T_2}{T_1} \right) = r_p * r_a * r_u * r_t \]  

(5)

Equations (4) and (5) may also be written as

\[ a_E = a_P + a_A + a_U \]  

(6)

\[ a_C = a_P + a_A + a_U + a_T \]  

(7)

where \( a_E = \ln(r_c) \), etc. Equations (6) and (7) are true by definition which means that naive regression or correlation approaches, that ignore the sum constraint, are potentially problematic in explaining how inter-country variation in \( a_p \), \( a_A \), and \( a_U \) influences inter-country variation in \( a_U \) and inter-country variation in \( a_P \), \( a_A \), \( a_U \) and \( a_T \) influences inter-country variation in \( a_C \). To overcome this problem, Preston (1996) has suggested to decompose the inter-country variation in \( a_E \) or \( a_C \) in terms of inter-country variation in \( a_P \), \( a_A \), \( a_U \) and \( a_T \). The inter-country variance in \( a_E \) can be decomposed as

\[ Var(a_E) = [Var(a_P) + Cov(a_P, a_A) + Cov(a_P, a_U)] + [Var(a_A) + Cov(a_A, a_P) + Cov(a_A, a_U)] + [Var(a_U) + Cov(a_U, a_P) + Cov(a_U, a_A)] \]  

(8)

where \( Var \) denotes the variance and \( Cov \) denotes the covariance. The contribution of the change in population to the change in energy use may now be measured in terms of the proportion of the inter-country variance in \( a_E \) explained by the inter-country variance in \( a_P \):

\[ V_{PE} = \frac{Var(a_P) + Cov(a_P, a_A) + Cov(a_P, a_U)}{Var(a_E)} \]  

(9)
Similarly, the inter-country variance in $a_c$ can be decomposed as:

$$Var(a_c) = [Var(a_p) + Cov(a_p, a_A) + Cov(a_p, a_U) + Cov(a_p, a_T)]$$

$$+ [Var(a_A) + Cov(a_A, r_p) + Cov(a_A, r_U) + Cov(a_A, r_T)]$$

$$+ [Var(a_U) + Cov(a_U, r_p) + Cov(a_U, a_A) + Cov(a_U, a_T)] + [Var(a_T) +$$

$$Cov(a_T, r_p) + Cov(a_T, a_A) + Cov(a_T, a_U)]$$

and the inter-country variance in $a_c$ attributed to the inter-country variance in $a_p$ to the inter-country variance in $a_c$ may be obtained as

$$V_{P/C} = \frac{Var(a_p) + Cov(a_p, a_A) + Cov(a_p, a_U) + Cov(a_p, a_T)}{Var(a_c)}$$

(10)

(11)

It may be noted that the contribution of inter-country variance in $a_p$ to the inter-country variance in $a_c$ or $a_e$ may be small for two reasons. First, the contribution of inter-country variance in $a_p$ to the inter-country variance in $a_e$ or $a_c$ may be small because $a_p$ varies little across countries so that the corresponding variance and covariance terms in equation (8) and (10) are small. Second, even if $a_p$ varies substantially across countries, the contribution of inter-country variance in $a_p$ to the inter-country variance in $a_e$ or $a_c$ may still be small because covariance terms in equations (8) and (10) are negative so that the algebraic sum of variance and covariance terms is small. In this case, equations (9) and (11) may not reflect the true importance of inter-country variance in $a_p$ in explaining the inter-country variance in $a_e$ or $a_c$. To circumvent this problem, it is suggested to use absolute values of covariance in equations (9) and (11) (Horvitz et al, 1997; Rees et al, 2010: Rees et al, 1996). In other words, the importance of the inter-country variance in $a_p$ to the inter-country variance in $a_e$ can then be obtained as

$$I_{P/E} = \frac{Var(a_p) + |Cov(a_p, a_A)| + |Cov(a_p, a_U)|}{S}$$

(12)
where \( S \) is the sum of the absolute values of the terms on the right-hand side of equation (8). Similarly, the relative importance of the inter-country variance in \( a_p \) to inter-country variance in \( a_c \) may then be obtained as

\[
I_{P/C} = \frac{\text{Var}(a_P) + |\text{Cov}(a_P,a_A)| + |\text{Cov}(a_P,a_U)| + |\text{Cov}(a_P,a_T)|}{V}
\]

(13)

where \( V \) is the sum of the absolute values of the terms on the right-hand side of equations (11).

On the other hand, the absolute change in the energy use between two points in time \( t_2 \) \( > \) \( t_1 \) can be decomposed as:

\[
d_E = E_2 - E_1 = (P_2 * A_2 * U_2) - (P_1 * A_1 * U_1)
\]

\[
= ((P_1 + d_P) * (A_1 + d_A) * (U_1 + d_U)) - (P_1 * A_1 * U_1)
\]

\[
= (d_P * A_1 * U_1) + (P_1 * d_A * U_1) + (P_1 * A_1 * d_U) + (d_P * d_A * U_1)
\]

\[
+ (d_P * A_1 * d_U) + (P_1 * d_A * d_U) + (d_P * d_A * d_U)
\]

\[
= \partial P + \partial A + \partial U + \partial P \partial A + \partial P \partial U + \partial A \partial U + \partial P \partial A \partial U
\]

(14)

where \( \partial P = (P_2 - P_1) \), etc. The first three terms on the right-hand side of equation (14) reflect the main effects, the next three terms reflect the first order or two-way interactions while the last term reflects the second order or three-way interaction among population, per capita real GDP and energy intensity of GDP. The advantage of the decomposition given by equation (14) is that it shows both direct and indirect effects of the change in population, per capita real GDP and energy intensity of GDP as they affect the change in the energy use. Although, interaction effects are difficult to interpret (Preston, Heuveline, Guillot, 2001), yet they provide useful insights into how population growth (increase in extensiveness of natural resources use) interacts with the change in per capita real GDP and the change in the energy intensity of GDP in influencing the change in natural resource use. The change in per capita GDP and the change in the energy intensity of GDP, in combination, determine the intensity of natural resource use.
Similarly, change in CO2 emissions can be decomposed as

\[ d_c = C_2 - C_1 = (P_2 * A_2 * U_2 * T_2) - (P_1 * A_1 * U_1 * T_1) \]

\[ = ((P_1 + d_P) * (A_1 + d_A) * (U_1 + d_U) * (T_1 + d_T)) - (P_1 * A_1 * U_1 * T_1) \]

\[ = (d_P * A_1 * U_1 * T_1) + (P_1 * d_A * U_1 * T_1) + (P_1 * A_1 * d_U * T_1) \]

\[ + (P_1 * A_1 * u_1 * d_T) + (d_P * d_A * U_1 * T_1) + (d_P * A_1 * d_U * T_1) \]

\[ + (d_P * A_1 * U_1 * d_T) + (d_P * d_A * d_U * T_1) + (d_P * d_A * U_1 * d_T) \]

\[ + (d_P * A_1 * U_1 * d_T) + (P_1 * d_A * d_U * d_T) + (d_P * d_A * d_U * d_T) \]

\[ = \delta P + \delta A + \delta U + \delta T + \delta P \delta A + \delta P \delta U + \delta P \delta T + \delta A \delta U + \delta A \delta T + \delta U \delta T + \]

\[ \delta P \delta A \delta U + \delta P \delta A \delta T + \delta P \delta U \delta T + \delta A \delta U \delta T + \delta P \delta A \delta U \delta T \] \hspace{1cm} (15)

In order to estimate total effect of population change on the change in energy use and CO2 emissions, it is necessary to distribute the interaction effect across interacting factors. Kim and Strobin (1984) have applied Goldfield’s rule (Durand, 1948, p.220) of “allocating interactions to different individual factors on the principle of equal distribution of all factors involved in each interaction” to allocate interaction effects to individual factors. In contrast, I have previously applied principal component analysis to determine relative weights of factors involved in interaction term (Chaurasia, 2017). Alternatively, weights may also be determined on the basis of the relative increase in factors involved in different interaction terms. For example, weight for the change in population in the interaction term \( d_P \delta A \) in equation (14) may be estimated as

\[ w_{P/A} = \frac{\ln(p_2)}{(\ln(p_2) + \ln(A_2))} \] \hspace{1cm} (16)

weights for other factors involved in different interaction terms may also be obtained in a similar manner.

The change in energy use and CO2 emissions between two points in time \( t_2 > t_1 \) may also be decomposed as

\[ d_E = \frac{d_E}{a_E} a_E = \frac{d_E}{a_E} a_P + \frac{d_E}{a_E} a_A + \frac{d_E}{a_E} a_U \] \hspace{1cm} (17)
and

\[
d_C = \frac{dc}{ac} a_C = \frac{dc}{ac} a_P + \frac{dc}{ac} a_A + \frac{dc}{ac} a_U + \frac{dc}{ac} a_T \tag{18}
\]

The decomposition given by equations (17) and (18) is known as logarithmic mean Divisia index (LMDI) factor decomposition. It is one of the index decomposition analysis (IDA) approaches widely used in energy and environmental economics (Chen et al, 2020; Hammond and Norman, 2012; Kumbaroglu, 2011). This decomposition was proposed by Ang and Liu (2001) and further developed by Ang (2004; 2005; 2015). Bacon and Bhattacharya (2007) have applied this approach to analyse the impact of growth on CO\(_2\) emissions during 1994-2004 in 70 countries of the world. The decomposition given by equations (17) and (18), however, provides little insight into direct and indirect effects of change in factors of energy use and CO\(_2\) emissions. In fact, decomposition given by equations (17) and (18) is actually an arithmetic manipulation of equations (6) and (7). Like equations (6) and (7), equations (17) and (18) also treat different factors as independent of each other when analysing the change in energy use and CO\(_2\) emissions.

Based on equation (14), the population effect of the change in energy use can be estimated as

\[
P_E = \partial P + \omega_{P/A} \partial P \partial A + \omega_{P/U} \partial P \partial U + \omega_{P/AU} \partial P \partial A \partial U \tag{19}
\]

Similarly, the population effect of the change in CO\(_2\) emissions can be estimated as

\[
P_C = \delta P + \nu_{P/A} \delta P \delta A + \nu_{P/U} \delta P \delta U + \nu_{P/T} \delta P \delta T + \nu_{P/AU} \delta P \delta A \delta U + \nu_{P/AT} \delta P \delta A \delta T + \nu_{P/UT} \delta P \delta U \delta T + \nu_{P/AUT} \delta P \delta A \delta U \delta T \tag{20}
\]

Data source

The analysis is based on estimates of total energy use, CO\(_2\) emissions and energy intensity of GDP for the world and for 44 countries for the period 1990-2019 prepared by Enerdata, an independent information and consultancy firm (Enerdata, 2020). In addition, estimates of population prepared by the United Nations Population Division (United Nations, 2019) have been used in the present analysis. The energy use has been defined as the balance of the primary energy
production, external energy trade, marine bunkers and stock changes including biomass. Estimates of energy use for the world include marine bunkers also but they are not included while estimating energy use in different countries (Enerdata, 2020).

On the other hand, estimates of CO$_2$ emissions are confined to emissions from fossil fuel combustion (coal, oil and gas) only. They have been estimated following the methodology proposed by the United Nations Framework Convention for Climate Change (UNFCCC, 2009). Moreover, the energy efficiency of GDP has been calculated as the ratio of total energy use to real GDP which has been measured in terms of 2015 US$ purchasing power parity while carbon intensity of energy use is measured as CO$_2$ emissions per unit energy use. The 44 countries that have been included in the present analysis accounted for more than 86 percent of the world energy use, almost 92 percent of the world CO$_2$ emissions and around 72 per cent of the world population in 2019. Collectively, they primarily determine the level and trend in world energy use and CO$_2$ emissions.

**Global trend in energy use and CO$_2$ emissions**

Total energy use in the world increased by more than 64 percent during 1990–2019, from 8756 million of tonnes of oil equivalent (Mtoe) in 1990 to 14378 Mtoe in 2019 whereas CO$_2$ emissions increased by more than 61 percent, from 20311 million tonnes (Mt) in 1990 to 32741 Mt in 2019. The world population increased by almost 45 percent during this period, from 5.327 billion to 7.713 billion, per capita real GDP at 2015 US$ purchasing power parity increased by almost 80 percent, from 9440 to 16982, energy intensity of GDP decreased by almost 37 percent, from 0.174 to 0.110 and carbon intensity of energy use decreased by less than 2 percent, from 2.320 to 2.277 between 1990 and 2019 (appendix table 1). The trend in energy use and CO$_2$ emissions and factors that determine them has, however, not been linear but changed frequently as revealed through “joinpoint” regression analysis (Kim et al, 2000) which studies the variation in trends over time. It identifies the time point(s), or joinpoint(s), at which the trend in the variable of interest changes and then estimates the trend between two joinpoint(s) in terms of annual percent change. The Joinpoint Trend Analysis software developed by National Cancer Institute of United States of America (NCI, 2013) has been used for carrying out the joinpoint regression analysis.
Application of joinpoint regression analysis reveals that the trend in world energy use changed three times during 1990–2019 (appendix table 2). The annual percent change in the world energy use was 1.401 percent during 1990–2001 but increased to 3.289 percent during 2001–2006. After 2006, the annual percent change decreased to 1.877 percent during 2006–2012 and to 1.184 percent during 2012–19. On the other hand, the trend in global CO₂ emissions changed four times. The annual percent change in global CO₂ emissions was just 0.120 percent during 1990–1992 but increased to 1.579 percent during 1993–2002 and to 4.396 percent during 2002–05. After 2005, the annual percent change in CO₂ emissions decreased to 2.219 percent during 2005–2012 and to only 0.683 percent during 2012–2019. Similarly, the trend in all the factors of energy use and CO₂ emissions also changed frequently. The trend in population changed five times; the trend in real per capita GDP changed three times; the trend in energy intensity of GDP changed five times; and the trend in carbon intensity of energy use changed two times. The annual percentage change in population decreased in every time period whereas the annual percentage change in real per capita GDP was the highest during 2003–2006. The decrease in energy intensity of GDP, as reflected in annual percentage change, was very rapid during 2004–2007 and again during 2010–2019. Finally, the carbon intensity of energy use increased during 1999–2013 but decreased quite rapidly thereafter.

The change in both energy use and CO₂ emissions varied widely across the 44 countries included in the present analysis (Table 3). The energy use and CO₂ emissions did not increase in all countries included in the present analysis. There are 11 countries where energy use decreased and 13 countries where CO₂ emissions decreased during the period under reference. The decrease in both energy use and CO₂ emissions has been the most rapid in Ukraine while the increase in both energy use and CO₂ emissions has been the most rapid in Malaysia. Among factors of energy use and CO₂ emissions, population increased in all but four countries – Poland, Romania, Russia and Ukraine – whereas per capita real GDP increased in all but three countries – Ukraine, Venezuela and United Arab Emirates. By comparison, energy intensity of GDP decreased in 36 countries while carbon intensity of energy use decreased in 30 countries.

More than two thirds of the global increase in energy use during 1990-2019 has been confined to only five countries – China, India, United States of America,
South Korea and Iran. These five countries accounted for more than 43 percent of the world population in 2019. On the other hand, more than 80 percent of the global increase in CO$_2$ emissions was confined to only four countries – China, India, Iran and Indonesia. These four countries accounted for almost 41 percent of the world population in 2019. China, the most populous country of the world and accounting for almost 19 percent of the world population in 2019, was responsible for almost 43 per cent of the global increase in the energy use and more than 60 per cent of the global increase in the CO$_2$ emissions during 1990-2019. India, the second most populous country of the world and accounting for almost 18 percent of the world population in 2019, accounted for around 11 percent of the increase in world energy use and around 13 per cent of the global increase in CO$_2$ emissions.

The decomposition of the inter-country variance in the increase in energy use and CO$_2$ emissions is presented in table 4 (see appendix). The primary contributor to inter-district variance in the change in both energy use and CO$_2$ emissions is found to be inter-country variance in the change in per capita real GDP followed by the change in the energy intensity of GDP. The inter-country variance in population change has been found to be responsible for around 20 per cent of the inter-country variance in the change in both energy use and CO$_2$ emissions. A more revealing observation of table 4 is that inter-country variance in the change in carbon intensity of energy use is found to be responsible for only around 7 per cent of the inter-country variance in the change in CO$_2$ emissions.

**Population effects of energy use and CO$_2$ emissions**

Table 5 (see appendix) decomposes the increase in world energy use and CO$_2$ emissions into its different factors in conjunction with equations (14) and (15). Between 1990 and 2015 total energy use in the world increased by 5622 Mtoe. Population growth accounted for an increase of 3933 Mtoe whereas increase in real per capita GDP accounted for an increase of 6664 Mtoe. However, decrease in energy intensity of GDP resulted in a decrease of 4975 Mtoe in the world energy use during this period. Similarly, population growth accounted for an increase of 8962 Mt in CO$_2$ emissions while increase in per capita real GDP accounted for an increase of 15181 Mt. By comparison, decrease in energy intensity of GDP resulted in a decrease of 11336 Mt while decrease in carbon intensity of energy use resulted in a decrease of only 377 Mt during 1990–2019.
The contribution of the change in different factors to the change in energy use (appendix table 6) and CO₂ emissions (appendix table 7) has varied widely across 44 countries. Ukraine is the only country where all factors contributed to the decrease in energy use and CO₂ emissions. On the other hand, Brazil is the only country where all factors contributed to increase in energy use and CO₂ emissions. There are 12 countries where energy intensity of GDP decreased but carbon intensity of energy use increased; 6 countries where energy intensity of GDP increased but carbon intensity of energy use decreased. This leaves only 24 countries where both energy intensity of GDP and carbon intensity of energy use decreased during 1990–2019.

An idea about the effect of population on the environment may be made by relating the change in energy use attributed to population change to the change in energy use attributed to change in energy intensity of GDP. This relationship may be captured by calculating the population effect coefficient of the change in energy use (PECₑ) as

\[
PECₑ = \begin{cases} 
-\left(\frac{d_P}{d_U}\right) & \text{if } P \text{ and } U \text{ change in opposite directions} \\
\left(\frac{d_P}{d_U}\right) & \text{if } P \text{ and } U \text{ change in the same direction}
\end{cases}
\]

The PECₑ reflects the proportion of the decrease in energy use attributed to the decrease in the energy intensity of GDP which is offset by the increase in energy use attributed to the increase in population irrespective of the change in energy use attributed to the change in per capita real GDP when population increases but the energy intensity of GDP decreases. Arguing in the same manner, the population effect coefficient of the change in CO₂ emissions (PECₓ) may be defined as

\[
PECₓ = \begin{cases} 
-\left(\frac{d_P}{d_U + d_T}\right) & \text{if } P \text{ and } (U + T) \text{ change in opposite directions} \\
\left(\frac{d_P}{d_U + d_T}\right) & \text{if } P \text{ and } (U + T) \text{ change in the same direction}
\end{cases}
\]
Table 8 (see appendix) gives the population effect coefficient of the change in energy use and CO$_2$ emissions for the world and for 44 countries. For the world as a whole, the population effect coefficient is 0.802 for energy use and 0.771 for CO$_2$ emissions. This means that more than 80 per cent of the decrease in energy use resulting from the reduction in the energy intensity of GDP has been offset by the increase in population. Similarly, over 77 per cent of the reduction in CO$_2$ emissions resulting from the decrease in the energy intensity of GDP and the decrease in the carbon intensity of energy use has been offset by the increase in population.

The population effect coefficient of energy use varies widely across 44 countries. The energy intensity of GDP decreased in 32 countries between 1990 and 2019 and the population effect coefficient, in these countries, ranged from just 0.047 in Czech Republic to 5.345 in Malaysia. A population effect coefficient of 0.047 implies that the increase in energy use as a result of the increase in population offset only 4.7 per cent of the decrease in energy use as a result of the decrease in energy intensity of GDP. Similarly, a population effect coefficient of 5.345 implies that that increase in energy use as a result of population increase is more than five times the decrease in energy use as a result of the decrease in energy intensity of GDP.

On the other hand, the energy intensity of GDP increased in eight countries and the population effect coefficient, in these countries, ranged from 0.677 in Iran to 24.011 in United Arab Emirates. This means that the increase in energy use as a result of population growth in Iran was almost 68 per cent of the increase in energy use as a result of the increase in energy intensity of GDP but 24 times higher in United Arab Emirates. Finally, in four countries, both population and energy intensity of GDP decreased during 1990-2019. In these countries, population effects coefficient ranged from 0.002 in Poland to 0.250 in Ukraine which means that the decrease in energy use as a result of decrease in population is almost negligible compared to the decrease in energy use as a result of the decrease in the energy intensity of GDP in Poland but 25 per cent in Ukraine. There is no country where population decreased but energy intensity of GDP increased during the study period. A similar pattern may also be observed in the population effect coefficient of CO$_2$ emissions with the only difference being that the variation of the population effect coefficient across different groups of countries is even wider.
Discussions and conclusions

The present analysis highlights the substantial impact of population growth on the increase in energy use and CO₂ emissions in the world during 1990-2019. The impact of population growth is further compounded because of the increase in per capita real GDP which is universally recognised as one of the key monetary indicators of social and economic development and of quality of life. The analysis also shows that, at the global level, the positive environmental effects of the decrease in energy intensity of GDP and carbon intensity of energy use can offset only a part of the negative environmental effects of population growth and increase in per capita real GDP. The positive environmental effect of the decrease in carbon intensity of energy use has, however, been marginal compared to the positive environmental effect of the decrease in the energy intensity of GDP.

The analysis suggests that reducing and ultimately achieving zero population growth can contribute significantly towards environmental sustainability by considerably decelerating the increase in energy use and CO₂ emissions in the world. However, such an option does not appear to be strategically viable in the context of United Nations 2030 Sustainable Development Agenda (United Nations, 2015) which characterises sustainable development in terms of economic growth, social inclusion and environmental sustainability. It is well known that population growth is an important contributor to economic growth (Peterson, 2017; Chaurasia, 2020). In India, for example, population growth during 2001-2011 accounted for almost 22 percent of the increase in the output of Indian economy (Chaurasia, 2019). Moreover, a low or zero population growth leads to an ageing population and insufficient people of productive age to support the economy (Pace, 1971). A certain minimum threshold of population growth, therefore, is necessary to lessen the burden of supporting a large number of old people (Peterson, 2017). At the same time, continued very low population growth for a long period of time may still lead to substantial increase in population (Piketty, 2014). For example, population growth at an average annual rate of 0.8 percent during 1700 to 2015 resulted in about 12 times increase in the world population (Maddison, 2001; World Bank, 2017).

Reducing population growth to very low levels will also have implications for the social inclusion component of United Nations 2030 Sustainable Development Agenda. The economic analysis of inequality indicates that lower population
growth will lead to increased global and national income inequality (Peterson, 2017). When the rate of return to capital is greater than the economic growth rate, the likely result is the concentration in the ownership of capital leading to increasing inequality (Piketty, 2014). The future, economic growth is likely to be slower than the rate of return on capital because the demographic component of economic growth will grow very little in the coming years (Piketty, 2015). Obviously, reducing and ultimately achieving zero population growth may not be a strategically viable option for realising the United Nations 2030 Sustainable Development Agenda.

The present analysis highlights the need of integrating population as a factor in environmental sustainability in the United Nations 2030 Sustainable Development Agenda. This integration must recognise that extensiveness, intensity and efficiency of natural resource use interact with each other to determine the extent of natural resource use and wastes generated. This integration is all the more important because the three factors of natural resource use are very much country specific. Unfortunately, the United Nations 2030 Sustainable Development Agenda pays only lop-sided attention to these interactions which are the key to sustaining life on the planet Earth.

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### Table 1: Energy use, CO$_2$ emissions, population, per capita real GDP, energy intensity of GDP and carbon intensity of energy use in the world, 1990–2019

| Year | Energy use (Mtoe) | CO$_2$ emissions (Mt) | Population (000) | Per capita real GDP (2015 US$ PPP) | Energy intensity of GDP | Carbon intensity of energy use |
|------|------------------|----------------------|------------------|-----------------------------------|------------------------|--------------------------------|
| 1990 | 8756             | 20311                | 5327231          | 9440                              | 0.174                  | 2.320                          |
| 1991 | 8811             | 20445                | 5414289          | 9399                              | 0.173                  | 2.320                          |
| 1992 | 8821             | 20382                | 5498920          | 9415                              | 0.170                  | 2.311                          |
| 1993 | 8911             | 20486                | 5581598          | 9439                              | 0.169                  | 2.299                          |
| 1994 | 8980             | 20585                | 5663150          | 9577                              | 0.166                  | 2.292                          |
| 1995 | 9209             | 21063                | 5744213          | 9752                              | 0.164                  | 2.287                          |
| 1996 | 9437             | 21526                | 5824892          | 9988                              | 0.162                  | 2.281                          |
| 1997 | 9536             | 21896                | 5905046          | 10244                             | 0.158                  | 2.296                          |
| 1998 | 9582             | 22054                | 5984794          | 10361                             | 0.155                  | 2.302                          |
| 1999 | 9788             | 22193                | 6064239          | 10581                             | 0.153                  | 2.267                          |
| 2000 | 10015            | 22836                | 6143494          | 10938                             | 0.149                  | 2.280                          |
| 2001 | 10103            | 23194                | 6222627          | 11055                             | 0.147                  | 2.296                          |
| 2002 | 10321            | 23511                | 6301773          | 11222                             | 0.146                  | 2.278                          |
| 2003 | 10685            | 24563                | 6381185          | 11500                             | 0.146                  | 2.299                          |
| 2004 | 11167            | 25708                | 6461159          | 11953                             | 0.145                  | 2.302                          |
| 2005 | 11471            | 26624                | 6541907          | 12360                             | 0.142                  | 2.321                          |
| 2006 | 11813            | 27454                | 6623518          | 12850                             | 0.139                  | 2.324                          |
| 2007 | 12132            | 28389                | 6705947          | 13364                             | 0.135                  | 2.340                          |
| 2008 | 12279            | 28597                | 6789089          | 13578                             | 0.133                  | 2.329                          |
| 2009 | 12177            | 28332                | 6872767          | 13364                             | 0.133                  | 2.327                          |
| 2010 | 12843            | 29918                | 6956824          | 13891                             | 0.133                  | 2.330                          |
| Year | Population | Energy Use | CO\textsubscript{2} Emissions | Growth Rate | CO\textsubscript{2} Emission Growth Rate |
|------|------------|------------|-------------------------------|-------------|----------------------------------------|
| 2011 | 13040      | 30699      | 7041194                       | 0.130       | 2.354                                  |
| 2012 | 13245      | 31184      | 7125828                       | 0.128       | 2.354                                  |
| 2013 | 13416      | 31748      | 7210582                       | 0.125       | 2.366                                  |
| 2014 | 13595      | 31811      | 7295291                       | 0.122       | 2.340                                  |
| 2015 | 13637      | 31759      | 7379797                       | 0.119       | 2.329                                  |
| 2016 | 13720      | 31704      | 7464022                       | 0.116       | 2.311                                  |
| 2017 | 13970      | 32099      | 7547859                       | 0.113       | 2.298                                  |
| 2018 | 14287      | 32805      | 7631091                       | 0.112       | 2.296                                  |
| 2019 | 14378      | 32741      | 7713468                       | 0.110       | 2.277                                  |
| Period    | Energy use annual % increase | Population annual % increase | Per capita real GDP carbon intensity of energy use annual % increase | Per capita real GDP energy use annual % increase | Carbon intensity of energy use 1990–2019 | Energy intensity of GDP 1990–2019 | Per capita GDP CO₂ emissions 1990–2019 | Number of jointpoints |
|----------|------------------------------|-----------------------------|------------------------------------------------------------------|-----------------------------------------------|------------------------------------------|----------------------------------------|--------------------------------------|----------------------|
| 1990–2001 | 1.401                        | 0.120                       | 1.612                                                            | 1.653                                         | 1.246                                    | 3.289                                  | 0.92                                | 3                    |
| 2001–2006 | 3.289                        | 1.579                       | 4.396                                                            | 4.396                                         | 1.328                                    | 6.292                                  | 1.109                               | 4                    |
| 2006–2012 | 1.877                        | 1.877                       | 2.219                                                            | 2.219                                         | 1.246                                    | 0.836                                  | 1.187                               | 5                    |
| 2012–2019 | 1.184                        | 0.683                       | 0.683                                                            | 0.683                                         | 1.109                                    | 1.187                                  | 1.187                               | 5                    |
| 1990–2019 | 1.770                        | 1.770                       | 1.770                                                            | 1.770                                         | 1.770                                    | 1.770                                  | 1.770                               | 5                    |

**Table 2: Annual percent increase in energy use and CO₂ emissions in the world, 1990–2019.**

**Source:** Author's calculations
Table 3: Energy use, CO₂ emissions, population, real per capita GDP, energy intensity of GDP and carbon intensity of energy use in 44 countries of the world 1990 and 2019.

| Country          | Energy use (Mtoe) | CO₂ emissions (Mt) | Population (000) | Per capita real GDP (2015 US$ PPP) | Energy intensity of GDP | Carbon intensity of GDP |
|------------------|-------------------|--------------------|------------------|-----------------------------------|------------------------|------------------------|
| Year             | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  |
| Algeria          | 22    | 62    | 53    | 147   | 25759 | 43053 | 10998 | 14547 | 0.078 | 0.099 | 2.388 | 2.368 |
| Argentina        | 46    | 82    | 101   | 171   | 32619 | 44781 | 12146 | 19071 | 0.116 | 0.097 | 2.195 | 2.070 |
| Australia        | 86    | 136   | 261   | 395   | 16961 | 25203 | 30276 | 47873 | 0.168 | 0.113 | 3.034 | 2.910 |
| Belgium          | 48    | 55    | 107   | 98    | 10007 | 11539 | 33281 | 47270 | 0.144 | 0.100 | 2.224 | 1.790 |
| Brazil           | 141   | 288   | 194   | 410   | 149003| 211050| 11045 | 15340 | 0.085 | 0.089 | 1.377 | 1.422 |
| Canada           | 211   | 295   | 430   | 569   | 27541 | 37411 | 32504 | 46086 | 0.236 | 0.171 | 2.036 | 1.927 |
| Chile            | 14    | 39    | 31    | 86    | 13275 | 18952 | 9146  | 23245 | 0.115 | 0.089 | 2.209 | 2.205 |
| China            | 874   | 3284  | 2257  | 9729  | 1176884| 1433784| 1572  | 17907 | 0.472 | 0.128 | 2.582 | 2.963 |
| Colombia         | 24    | 40    | 46    | 83    | 33103 | 50339 | 8254  | 14535 | 0.089 | 0.055 | 1.902 | 2.059 |
| Czech Republic   | 50    | 43    | 147   | 100   | 10341 | 10689 | 22026 | 37486 | 0.219 | 0.108 | 2.960 | 2.311 |
| Egypt            | 32    | 95    | 78    | 215   | 56134 | 100388| 6299  | 12173 | 0.091 | 0.077 | 2.432 | 2.272 |
| France           | 225   | 241   | 365   | 302   | 56667 | 65130 | 32854 | 44472 | 0.121 | 0.083 | 1.627 | 1.250 |
| Germany          | 351   | 296   | 953   | 673   | 79054 | 83517 | 34247 | 50042 | 0.130 | 0.071 | 2.714 | 2.277 |
| India            | 306   | 913   | 523   | 2222  | 873278| 1366418| 2035  | 7541  | 0.172 | 0.089 | 1.710 | 2.433 |
Table 3: Continued

| Country     | Energy use (Mtoe) | CO2 emissions (Mt) | Population (000) | Per capita real GDP (2015 US$ PPP) | Energy intensity of GDP | Carbon intensity of GDP |
|-------------|-------------------|--------------------|------------------|----------------------------------|------------------------|------------------------|
| Year        | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  | 1990  | 2019  |
| Indonesia   | 99    | 269   | 148   | 581   | 181413 | 270626 | 4940  | 12875 | 0.110 | 0.077 | 1.498 | 2.159 |
| Iran        | 69    | 258   | 181   | 638   | 56366  | 82914  | 12137 | 17346 | 0.101 | 0.179 | 2.615 | 2.476 |
| Italy       | 147   | 149   | 398   | 318   | 57048  | 60550  | 33259 | 38375 | 0.077 | 0.064 | 2.711 | 2.131 |
| Japan       | 440   | 421   | 1040  | 1045  | 124505 | 126860 | 32398 | 42034 | 0.109 | 0.079 | 2.362 | 2.483 |
| Kazakhstan  | 73    | 89    | 236   | 266   | 16384  | 18551  | 13907 | 27200 | 0.322 | 0.176 | 3.217 | 3.000 |
| Kuwait      | 9     | 36    | 28    | 94    | 2095   | 4207   | 40480 | 70181 | 0.107 | 0.120 | 3.081 | 2.659 |
| Malaysia    | 21    | 93    | 51    | 244   | 18030  | 31950  | 11274 | 30986 | 0.104 | 0.094 | 2.391 | 2.624 |
| Mexico      | 124   | 178   | 264   | 433   | 83943  | 127576 | 14193 | 18703 | 0.104 | 0.074 | 2.135 | 2.441 |
| Netherlands | 67    | 71    | 163   | 170   | 14965  | 17097  | 34378 | 54727 | 0.129 | 0.076 | 2.455 | 2.398 |
| New Zealand | 14    | 20    | 22    | 33    | 3398   | 4783   | 24675 | 40476 | 0.163 | 0.104 | 1.582 | 1.624 |
| Nigeria     | 66    | 168   | 28    | 87    | 95212  | 200964 | 3589  | 5655  | 0.194 | 0.148 | 0.426 | 0.518 |
| Norway      | 21    | 27    | 28    | 40    | 4247   | 5379   | 40412 | 61722 | 0.123 | 0.082 | 1.323 | 1.471 |
| Poland      | 103   | 103   | 356   | 302   | 37960  | 37888  | 10937 | 31799 | 0.248 | 0.085 | 3.450 | 2.939 |
| Portugal    | 17    | 22    | 40    | 48    | 9895   | 10226  | 22699 | 33031 | 0.075 | 0.065 | 2.371 | 2.154 |
| Romania     | 62    | 34    | 163   | 75    | 23489  | 19365  | 11754 | 27046 | 0.224 | 0.065 | 2.630 | 2.213 |
| Country                | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 | 2070 | 2075 |
|------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Russia                 | 879  | 779  | 2189 | 1754 | 147532| 145872| 20362| 25450| 0.293| 0.210| 2.491| 2.251| 2.891| 2.684| 2.582| 2.215| 1.963|
| Saudi Arabia           | 58   | 207  | 156  | 534  | 16234 | 3469  | 45603| 51680| 0.078| 0.117| 2.684| 2.582| 2.808| 3.301| 2.808| 2.684| 2.582|
| South Africa           | 90   | 135  | 252  | 447  | 36801 | 58558 | 10573| 12837| 0.231| 0.180| 2.808| 3.301| 2.591| 2.180| 2.180| 2.180| 2.180|
| South Korea            | 94   | 298  | 243  | 650  | 42918 | 51225 | 12157| 39545| 0.180| 0.147| 2.591| 2.180| 1.113| 0.835| 1.113| 0.835| 0.835|
| Spain                  | 90   | 125  | 205  | 240  | 39203 | 46737 | 25500| 38603| 0.090| 0.069| 2.281| 1.920| 2.412| 2.555| 2.412| 2.555| 2.555|
| Sweden                 | 47   | 47   | 53   | 39   | 8567  | 10036 | 32754| 51311| 0.168| 0.091| 1.113| 0.835| 2.412| 1.905| 2.412| 1.905| 1.905|
| Taiwan                 | 48   | 110  | 115  | 280  | 20479 | 23774 | 18381| 4.013| 0.104| 0.111| 1.929| 1.905| 2.576| 2.563| 2.576| 2.563| 2.563|
| Thailand               | 42   | 142  | 81   | 271  | 56558 | 69626 | 7106 | 18381| 1.04| 0.111| 1.929| 1.905| 2.576| 2.563| 2.576| 2.563| 2.563|
| Turkey                 | 51   | 147  | 133  | 377  | 53922 | 83430 | 12532| 27754| 0.076| 0.063| 2.576| 2.563| 2.576| 2.563| 2.576| 2.563| 2.563|
| Ukraine                | 252  | 89   | 690  | 177  | 51463 | 43994 | 11268| 8689 | 0.435| 0.232| 2.739| 1.990| 2.739| 1.990| 2.739| 1.990| 1.990|
| United Arab Emirates   | 20   | 69   | 52   | 199  | 1828  | 9771  | 119987| 71246| 0.093| 0.100| 2.553| 2.868| 2.553| 2.868| 2.553| 2.868| 2.868|
| United Kingdom         | 206  | 171  | 556  | 346  | 57134 | 67530 | 28945| 43190| 0.125| 0.059| 2.700| 2.023| 2.700| 2.023| 2.700| 2.023| 2.023|
| United States          | 1910 | 2213 | 4866 | 4920 | 252120 | 329065| 39199| 60544| 0.193| 0.111| 2.548| 2.223| 2.548| 2.223| 2.548| 2.223| 2.223|
| Uzbekistan             | 46   | 37   | 116  | 89   | 20398 | 32982 | 3298 | 7299 | 0.689| 0.152| 2.509| 2.440| 2.509| 2.440| 2.509| 2.440| 2.440|
| Venezuela              | 40   | 39   | 94   | 87   | 19633 | 28516 | 15613| 6608 | 0.129| 0.205| 2.368| 2.237| 2.368| 2.237| 2.368| 2.237| 2.237|
Table 4: Decomposition of the inter-country variance in the rate of change in energy use and CO₂ emissions, 1990–2019

| Particulars       | Variance and covariance | Variance explained | Relative importance |
|-------------------|-------------------------|--------------------|---------------------|
|                   |                         | Total  | Percent |                        |                       |
| **Energy use (E)**|                         |        |         |                        |                       |
| Var (E)           |                         | 0.349  | 100.00  | 100.00                |                       |
| Var (E) explained by P |                 | 0.113  | 32.47   | 19.63                |                       |
| Var (P)           |                         | 0.091  |         |                       |                       |
| Cov (PA)          |                         | -0.032 |         |                       |                       |
| Cov (PU)          |                         | 0.054  |         |                       |                       |
| Var (E) explained by U |                 | 0.124  | 33.54   | 37.35                |                       |
| Var (U)           |                         | 0.176  |         |                       |                       |
| Cov (UP)          |                         | 0.054  |         |                       |                       |
| Cov (UA)          |                         | -0.106 |         |                       |                       |
| **CO₂ emissions (C)**|                       |        |         |                        |                       |
| Var (C)           |                         | 0.475  | 100.00  | 100.00                |                       |
| Var (C) explained by P |                 | 0.136  | 28.61   | 19.42                |                       |
| Var (P)           |                         | 0.091  |         |                       |                       |
| Cov (PA)          |                         | -0.032 |         |                       |                       |
| Cov (PU)          |                         | 0.054  |         |                       |                       |
| Cov (PT)          |                         | 0.023  |         |                       |                       |
| Var (C) explained by A |                 | 0.249  | 28.08   | 39.86                |                       |
| Var (A)           |                         | 0.133  |         |                       |                       |
| Cov (AP)          |                         | -0.032 |         |                       |                       |
| Cov (AU)          |                         | -0.106 |         |                       |                       |
| Cov (AT)          |                         | 0.022  |         |                       |                       |
**Table 4: Continued**

| Particulars          | Variance and covariance | Variance explained | Relative importance |
|----------------------|-------------------------|--------------------|---------------------|
|                      |                         | Total | Percent |                     |
| Var (Q) explained by $U$ | 0.131  | 27.50  | 33.41   |
| Var ($U$)             | 0.176                  |       |         |
| Cov ($UP$)            | 0.054                  |       |         |
| Cov ($UA$)            | -0.106                 |       |         |
| Cov ($UT$)            | 0.007                  |       |         |
| Var (Q) explained by $T$ | 0.076  | 15.82  | 7.32    |
| Var ($T$)             | 0.024                  |       |         |
| Cov ($TP$)            | 0.023                  |       |         |
| Cov ($TA$)            | 0.022                  |       |         |
| Cov ($TU$)            | 0.007                  |       |         |

SOURCE: AUTHOR'S CALCULATIONS
Table 5: Decomposition of the change in energy use and CO$_2$ emissions in the World during 1990–2019

| Particulars | Energy use | CO$_2$ emissions |
|-------------|------------|------------------|
|             | Total | %   | Total | %   |
| Total change during 1990–2019 | 5622 |   | 12430 |   |
| Change attributed to population | 4186 | 74.47 | 9541 | 76.76 |
| Direct | 3922 |   | 9098 |   |
| Indirect | 264 |   | 443 |   |
| Through A | 1212 |   | 2810 |   |
| Through U | -645 |   | -1497 |   |
| Through T | -159 |   |   |   |
| Through A and U | -302 |   | -701 |   |
| Through A and TT | -50 |   |   |   |
| Through U and T | 27 |   |   |   |
| Through A, U and T | 13 |   |   |   |
| Change attributed to per capita real GDP | 6991 | 124.36 | 15929 | 128.15 |
| Direct | 6997 |   | 16229 |   |
| Indirect | -5 |   | -300 |   |
| Through P | 1922 |   | 4459 |   |
| Through U | -1448 |   | -3359 |   |
| Through T | -288 |   |   |   |
| Through P and U | -479 |   | -1112 |   |
| Through P and T | -80 |   |   |   |
| Through U and T | 60 |   |   |   |
| Through P, U and T | 20 |   |   |   |
### Table 5: Continued

| Particulars                                      | Energy use | CO₂ emissions |
|-------------------------------------------------|------------|---------------|
|                                                  | Total      | %             | Total      | %             |
| Change attributed to energy intensity of GDP     |            |               |            |               |
| Direct -5556                                    | -98.83     | -12659        | -101.84    |
| Indirect -3237                                   |            | -7508         |
| Through P -804                                   |            | -1866         |
| Through A -1138                                  |            | -2640         |
| Through T 132                                    |            |               |
| Through P and A -377                             |            | -61487        |
| Through P and T 33                               |            |               |
| Through A and T 47                               |            |               |
| Through P, A and T 16                            |            |               |
| Change attributed to carbon intensity of energy use |            | -382         | -3.07       |
| Direct -371                                     |            |               |
| Indirect -10                                     |            |               |
| Through P -8                                     |            |               |
| Through A -9                                     |            |               |
| Through U 5                                      |            |               |
| Through P and A -3                               |            |               |
| Through P and U 1                                |            |               |
| Through A and U 2                                |            |               |
| Through P, A and U 1                             |            |               |

*Source: Author’s Calculations*
### Table 6: Population effects of energy use (Mtoe) in 44 countries, 1990–2019

| Country      | Increase in energy use during 1990–2015 | Increase in energy use attributed to increase in population | Decomposition of population effect | Decomposition of indirect effect |
|--------------|----------------------------------------|-----------------------------------------------------------|-----------------------------------|----------------------------------|
|              |                                        |                                                            | Direct               | Indirect              | Through A | Through U | Through A and U |
| Algeria      | 39.771                                 | 21.334                                                    | 14.894               | 6.440                 | 3.112      | 2.695      | 0.633           |
| Argentina    | 36.435                                 | 18.831                                                    | 17.175               | 1.656                 | 4.040      | -1.833     | -0.551          |
| Australia    | 49.764                                 | 43.759                                                    | 41.864               | 1.896                 | 11.281     | -6.858     | -2.528          |
| Belgium      | 6.864                                  | 7.441                                                     | 7.335                | 0.106                 | 0.891      | -0.629     | -0.156          |
| Brazil       | 147.614                                | 72.947                                                    | 58.579               | 14.368                | 11.722     | 2.185      | 0.461           |
| Canada       | 84.423                                 | 77.575                                                    | 75.637               | 1.938                 | 14.770     | -10.119    | -2.713          |
| Chile        | 25.191                                 | 7.265                                                     | 5.992                | 1.273                 | 2.552      | -0.793     | -0.486          |
| China        | 2409.378                               | 248.865                                                   | 190.820              | 58.044                | 148.820    | -18.268    | -72.507         |
| Colombia     | 16.229                                 | 13.426                                                    | 12.614               | 0.813                 | 4.084      | -2.232     | -1.039          |
| Czech Republic | -6.646                                | 1.693                                                     | 1.677                | 0.015                 | 0.069      | -0.038     | -0.016          |
| Egypt        | 62.331                                 | 32.043                                                    | 25.416               | 6.627                 | 11.110     | -2.999     | -1.484          |
| France       | 16.703                                 | 33.823                                                    | 33.552               | 0.271                 | 3.737      | -2.837     | -0.629          |
| Germany      | -55.551                                | 20.010                                                    | 19.821               | 0.189                 | 1.156      | -0.748     | -0.219          |
| India        | 607.539                                | 215.983                                                   | 172.616              | 43.367                | 118.953    | -33.724    | -41.862         |
| Indonesia    | 170.426                                | 58.361                                                    | 48.516               | 9.844                 | 22.952     | -7.676     | -5.432          |
| Country      | Population 1990 | Energy Use 1990 | CO2 Emissions 1990 | Population Change 1990-2019 | Energy Use Change 1990-2019 | CO2 Emissions Change 1990-2019 |
|-------------|-----------------|-----------------|-------------------|-----------------------------|-----------------------------|--------------------------------|
| Iran        | 188.271         | 53.197          | 32.638            | 20.559                      | 7.276                       | 10.121                         |
| Italy       | 2.275           | 9.008           | 9.008             | 0.000                       | 0.407                       | -0.371                         |
| Japan       | -19.416         | 8.348           | 8.329             | 0.019                       | 0.166                       | -0.126                         |
| Kazakhstan  | 15.142          | 10.043          | 9.717             | 0.326                       | 1.451                       | -0.751                         |
| Kuwait      | 26.406          | 14.307          | 9.180             | 5.126                       | 3.764                       | 0.948                          |
| Malaysia    | 71.623          | 24.345          | 16.380            | 7.965                       | 10.350                      | -1.401                         |
| Mexico      | 53.846          | 64.100          | 64.287            | -0.187                      | 12.312                      | -10.142                        |
| Netherlands | 4.574           | 9.606           | 9.475             | 0.193                       | 1.249                       | -0.783                         |
| New Zealand | 6.507           | 5.813           | 5.568             | 0.244                       | 1.457                       | -0.870                         |
| Nigeria     | 101.351         | 82.049          | 73.785            | 8.264                       | 26.398                      | -12.969                        |
| Norway      | 6.139           | 5.767           | 5.614             | 0.153                       | 1.060                       | -0.688                         |
| Poland      | -0.340          | -0.197          | -0.197            | 0.000                       | -0.001                      | 0.000                          |
| Portugal    | 5.324           | 0.566           | 0.561             | 0.005                       | 0.021                       | -0.014                         |
| Romania     | -28.185         | -11.649         | -10.882           | -0.767                      | -2.663                      | 1.040                          |
| Russia      | -99.337         | -9.896          | -9.883            | -0.013                      | -0.119                      | 0.092                          |
| Saudi Arabia| 148.933         | 94.900          | 64.439            | 30.461                      | 7.355                       | 20.628                         |
| South Africa| 45.590          | 52.188          | 53.043            | -0.855                      | 8.011                       | -7.589                         |
| South Korea | 204.168         | 21.129          | 18.187            | 2.941                       | 5.344                       | -1.553                         |
| Spain       | 34.707          | 17.932          | 17.315            | 0.617                       | 2.649                       | -1.607                         |
| Sweden      | -0.132          | 8.255           | 8.093             | 0.162                       | 1.195                       | -0.761                         |
Table 6: Continued

| Country          | Increase in energy use during 1990–2015 | Increase in energy use attributed to increase in population | Decomposition of population effect | Decomposition of indirect effect |
|------------------|----------------------------------------|----------------------------------------------------------|-----------------------------------|--------------------------------|
|                  |                                        |                                                          | Direct | Indirect | Through A | Through U | Through A and U |
| Taiwan           | 61.945                                 | 8.361                                                    | 7.683  | 0.678    | 1.831      | -0.690     | -0.463          |
| Thailand         | 100.515                                | 13.117                                                   | 9.692  | 3.426    | 2.760      | 0.492      | 0.174           |
| Turkey           | 95.578                                 | 35.218                                                   | 28.152 | 7.066    | 12.119     | -3.300     | -1.753          |
| Ukraine          | -163.247                               | -30.605                                                  | -36.579| 5.974    | 3.151      | 3.409      | -0.586          |
| United Arab Emirates | 49.065                            | 65.457                                                   | 88.714 | -23.257  | -27.488    | 6.157      | -1.926          |
| United Kingdom   | -35.148                                | 38.073                                                   | 37.476 | 0.598    | 5.434      | -3.601     | -1.236          |
| United States    | 303.544                                | 594.345                                                  | 582.897| 11.449   | 120.589    | -80.495    | -28.645         |
| Uzbekistan       | -9.713                                 | 31.639                                                   | 28.604 | 3.035    | 13.079     | -5.379     | -4.665          |
| Venezuela        | -0.824                                 | 18.131                                                   | 17.878 | 0.252    | -3.121     | 4.717      | -1.343          |

SOURCE: AUTHOR’S CALCULATIONS
### Table 7: Population effects of the increase in CO₂ emissions (Mt) in 44 countries, 1990–2019

| Country         | Increase in CO₂ emissions | Population effects of CO₂ emissions |
|-----------------|---------------------------|-------------------------------------|
|                 | Total                     | Direct                              | Indirect | Indirect effect through |
|                 |                           |                                     | A        | U       | T       | AU      | AT      | UT      | AUT     |
| Algeria         | 93.727                    | 50.522                              | 35.566   | 14.956  | 7.432   | 6.434   | -0.293  | 1.511   | -0.062  | -0.053  | -0.013  |
| Argentina       | 69.611                    | 39.320                              | 37.706   | 1.615   | 8.870   | -4.025  | -1.821  | -1.209  | -0.472  | 0.206   | 0.065   |
| Australia       | 134.061                   | 127.836                             | 127.025  | 0.811   | 34.230  | -20.808 | -4.718  | -7.670  | -1.340  | 0.812   | 0.305   |
| Belgium         | -8.522                    | 15.265                              | 16.316   | -1.050  | 1.981   | -1.399  | -1.262  | -0.346  | -0.269  | 0.191   | 0.054   |
| Brazil          | 216.278                   | 103.499                             | 80.685   | 22.814  | 16.145  | 3.010   | 2.411   | 0.635   | 0.503   | 0.091   | 0.020   |
| Canada          | 139.600                   | 150.748                             | 153.999  | -3.250  | 30.071  | -20.602 | -7.003  | -5.524  | -1.489  | 1.016   | 0.281   |
| Chile           | 55.474                    | 16.017                              | 13.238   | 2.779   | 5.638   | -1.751  | -0.028  | -1.074  | -0.012  | 0.004   | 0.002   |
| China           | 7472.341                  | 706.149                             | 492.605  | 213.544 | 384.179 | -47.159 | 42.868  | -187.178| 53.941  | -6.383  | -26.722 |
| Colombia        | 37.221                    | 27.322                              | 23.994   | 3.328   | 7.769   | -4.247  | 1.665   | -1.976  | 0.593   | -0.322  | -0.155  |
| Czech Republic  | -47.689                   | 4.878                               | 4.965    | -0.087  | 0.204   | -0.113  | -0.129  | -0.046  | -0.031  | 0.019   | 0.008   |
| Egypt           | 136.417                   | 73.255                              | 61.806   | 11.449  | 27.018  | -7.292  | -3.646  | -3.610  | -1.688  | 0.440   | 0.227   |
| France          | -63.627                   | 50.646                              | 54.573   | -3.926  | 6.078   | -4.614  | -4.368  | -1.023  | -0.881  | 0.704   | 0.179   |
| Germany         | -279.773                  | 52.218                              | 53.789   | -1.571  | 3.138   | -2.031  | -2.063  | -0.595  | -0.360  | 0.258   | 0.082   |
| India           | 1699.515                  | 465.911                             | 295.197  | 170.714 | 203.426 | -57.672 | 69.834  | -71.590 | 71.657  | -18.513 | -26.428 |
| Indonesia       | 433.168                   | 109.761                             | 72.680   | 37.081  | 34.384  | -11.499 | 16.756  | -8.137  | 11.953  | -3.418  | -2.959  |
| Iran            | 456.534                   | 132.448                             | 85.356   | 47.092  | 19.028  | 26.469  | -3.978  | 8.270   | -0.943  | -1.332  | -0.422  |
### Table 7: Continued

| Country      | Increase in CO\(_2\) emissions | Population effects of CO\(_2\) emissions |          |          |          |          |
|--------------|----------------------------------|-------------------------------------------|----------|----------|----------|----------|
|              |                                  | Total| Direct| Indirect | Indirect effect through |
|              |                                  |      |       |          | A| U| T| AU| AT| UT| AUT |
| Italy        | -80.184                          | 23.395| 24.418| -1.023   | 1.104| -1.006| -1.036| -0.098| -0.108| 0.109| 0.013 |
| Japan        | 4.817                            | 19.997| 19.676| 0.321    | 0.393| -0.298| 0.275| -0.050| 0.017| -0.013| -0.002 |
| Kazakhstan   | 29.525                           | 30.895| 31.259| -0.364   | 4.669| -2.416| -1.348| -1.205| -0.289| 0.149| 0.077 |
| Kuwait       | 66.353                           | 38.962| 28.289| 10.673   | 11.599| 2.921| -3.204| 1.277| -1.423| -0.339| -0.158 |
| Malaysia     | 192.851                          | 63.262| 39.171| 24.091   | 24.750| -3.350| 3.275| -2.353| 2.272| -0.286| -0.217 |
| Mexico       | 169.200                          | 151.650| 137.282| 14.368   | 26.293| -21.657| 14.881| -5.034| 3.153| -2.630| -0.637 |
| Netherlands  | 7.130                            | 23.264| 23.263| 0.001    | 3.066| -1.922| -0.464| -0.669| 0.069| 0.044| 0.015 |
| New Zealand  | 11.147                           | 9.425| 8.811| 0.615    | 2.305| -1.376| 0.218| -0.542| 0.060| -0.036| -0.014 |
| Nigeria      | 58.606                           | 41.013| 31.453| 9.560    | 11.253| -5.528| 5.371| -2.202| 2.085| -1.000| -0.419 |
| Norway       | 12.142                           | 8.221| 7.427| 0.793    | 1.402| -0.911| 0.573| -0.289| 0.135| -0.087| -0.029 |
| Poland       | -53.642                          | -0.678| -0.679| 0.001    | -0.002| 0.001| 0.001| 0.000| 0.000| 0.000| 0.000 |
| Portugal     | 7.830                            | 1.309| 1.330| -0.021   | 0.049| -0.033| -0.031| -0.005| -0.004| 0.002| 0.000 |
| Romania      | -88.213                          | -28.010| -28.621| 0.611    | -7.005| 2.735| 2.396| 2.254| 0.951| -0.387| -0.332 |
| Russia       | -434.364                         | -24.413| -24.618| 0.205    | -0.297| 0.229| 0.238| 0.035| 0.020| -0.017| -0.003 |
| Saudi Arabia | 378.647                          | 245.472| 172.959| 72.514   | 19.741| 55.366| -6.247| 6.652| -0.718| -2.035| -0.245 |
| South Africa | 194.715                          | 165.537| 148.958| 16.578   | 22.498| -21.313| 19.392| -3.586| 3.170| -3.048| -0.534 |
| Country          | 1990   | 2000   | 2010   | 2015   | 2019   | 2020   | 2021   | 2022   | 2023   | 2024   | 2025   | 2026   | 2027   | 2028   | 2029   |
|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| South Korea      | 406.441| 49.771 | 47.129 | 2.642  | 13.849 | -4.024 | -3.784 | -2.203 | -1.950 | 0.439  | 0.315  |
| Spain            | 34.130 | 37.548 | 39.493 | -1.944 | 6.042  | -3.665 | -3.156 | -0.970 | -0.740 | 0.417  | 0.128  |
| Sweden           | -13.237| 8.381  | 9.011  | -0.630 | 1.331  | -0.848 | -0.799 | -0.303 | -0.226 | 0.154  | 0.061  |
| Taiwan           | 165.149| 21.057 | 18.531 | 2.526  | 4.415  | -1.663 | 0.795  | -1.118 | 0.251  | -0.090 | -0.064 |
| Thailand         | 190.465| 25.003 | 18.696 | 6.307  | 5.324  | 0.949  | -0.220 | 0.335  | -0.066 | -0.011 | -0.004 |
| Turkey           | 244.303| 90.270 | 72.523 | 17.747 | 31.220 | -8.502 | -0.363 | -4.516 | -0.158 | 0.043  | 0.023  |
| Ukraine          | -513.545| -77.606| -100.171| 22.565 | 8.628  | 9.336  | 9.020  | -1.605 | -1.336 | -1.814 | 0.336  |
| United Arab Emirates | 147.118 | 186.243| 226.522| -40.278| -70.188| 15.721 | 26.072 | -4.918 | -8.204 | 1.814  | -0.576 |
| United Kingdom   | -210.520| 93.609 | 101.196| -7.586 | 14.673 | -9.723 | -9.304 | -3.336 | -2.438 | 1.856  | 0.686  |
| United States    | 54.310 | 1387.020| 1485.056| -98.036| 307.226| -205.079| -125.223| -72.979| -32.792| 22.419 | 8.393  |
| Uzbekistan       | -26.905| 77.318 | 71.770 | 5.548  | 32.817 | -13.498| -1.868 | -11.705| -0.884 | 0.367  | 0.319  |
| Venezuela        | -7.023 | 40.888 | 42.342 | -1.454 | -7.392 | 11.171 | -2.033 | -3.182 | 0.391  | -0.579 | 0.170  |

SOURCE: AUTHOR’S CALCULATIONS
Table 8: Population effect coefficient in the world and in 44 countries.

| World/Country     | Population effect coefficient |
|-------------------|-------------------------------|
|                   | Energy use | CO2 missions |
| World             | 0.754      | 0.732        |
| Algeria           | 2.598      | 2.661        |
| Argentina         | 1.797      | 1.393        |
| Australia         | 0.964      | 0.889        |
| Belgium           | 0.381      | 0.250        |
| Brazil            | 11.352     | 6.482        |
| Canada            | 0.940      | 0.816        |
| Chile             | 1.393      | 1.385        |
| China             | 0.070      | 0.071        |
| Colombia          | 0.841      | 0.963        |
| Czech Republic    | 0.046      | 0.039        |
| Egypt             | 4.546      | 3.308        |
| France            | 0.367      | 0.228        |
| Germany           | 0.093      | 0.078        |
| India             | 0.547      | 0.845        |
| Indonesia         | 1.084      | 23.785       |
| Iran              | 0.612      | 0.649        |
| Italy             | 0.316      | 0.148        |
| Japan             | 0.058      | 0.066        |
| Kazakhstan        | 0.185      | 0.171        |
| Kuwait            | 9.851      | 22.766       |
| Malaysia          | 8.224      | 46.963       |
| Mexico            | 1.255      | 1.942        |
| Netherlands       | 0.240      | 0.231        |
| New Zealand       | 0.726      | 0.760        |
| Nigeria           | 3.141      | 8.501        |
| Country              | POPULATION EFFECTS | CO₂ EMISSIONS |
|----------------------|--------------------|---------------|
| Norway               | 0.557              | 0.713         |
| Poland               | 0.001              | 0.002         |
| Portugal             | 0.236              | 0.142         |
| Romania              | -0.176             | -0.160        |
| Russia               | 0.035              | 0.028         |
| Saudi Arabia         | 2.169              | 2.306         |
| South Africa         | 1.950              | 5.006         |
| South Korea          | 0.826              | 0.456         |
| Spain                | 0.636              | 0.397         |
| Sweden               | 0.253              | 0.188         |
| Taiwan               | 0.299              | 0.331         |
| Thailand             | 4.002              | 4.816         |
| Turkey               | 2.802              | 2.744         |
| Ukraine              | 0.351              | 0.239         |
| United Arab Emirates | 41.380             | 15.822        |
| United Kingdom       | 0.229              | 0.180         |
| United States        | 0.462              | 0.382         |
| Uzbekistan           | 0.328              | 0.324         |
| Venezuela            | 0.792              | 0.889         |

SOURCE: AUTHOR'S CALCULATIONS