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PEER REVIEWED ARTICLE

Population effects of increase in world energy use and CO_2 emissions: 1990–2019

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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

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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 prevalent 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 round 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 gasses such as carbon dioxide (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 CO_2 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 CO_2 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

$$E = P * \left(\frac{E}{P}\right) \tag{1}$$

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

$$E = P * \left(\frac{G}{P}\right) * \left(\frac{E/P}{G/P}\right) = P * A * U \tag{2}$$

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 CO_2 emissions, as a result of energy use may be written as

$$C = E * \left(\frac{C}{E}\right) = P * \left(\frac{E}{P}\right) * \left(\frac{C}{E}\right) = P * \left(\frac{G}{P}\right) * \left(\frac{E/P}{G/P}\right) * \left(\frac{C/P}{E/P}\right) = P * A * U * T \tag{3}$$

where $T=(C/P)/(E/P)=(C/E)$ is CO_2 emissions per unit energy use and is termed as carbon intensity of energy use. The change in energy use and CO_2 emissions between two points in time $t_2 > t_1$, can be captured in relative terms and in absolute terms. In relative terms, the change in energy use and CO_2 emissions can be written as

$$r_E = \left(\frac{E_2}{E_1}\right) = \left(\frac{P_2}{P_1}\right) * \left(\frac{A_2}{A_1}\right) * \left(\frac{U_2}{U_1}\right) = r_P * r_A * r_U \tag{4}$$

$$r_C = \left(\frac{C_2}{C_1}\right) = \left(\frac{P_2}{P_1}\right) * \left(\frac{A_2}{A_1}\right) * \left(\frac{U_2}{U_1}\right) * \left(\frac{T_2}{T_1}\right) = r_P * r_A * r_U * r_T \quad (5)$$

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

$$a_E = a_P + a_A + a_U \quad (6)$$

$$a_C = a_P + a_A + a_U + a_T \quad (7)$$

where a_E=ln(r_E), 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

$$Var(a_E) = [Var(a_P) + Cov(a_P, a_A) + Cov(a_P, a_U)] + [Var(a_A) + Cov(a_A, a_P) + Cov(a_A, a_U)] + [Var(a_U) + Cov(a_U, a_P) + Cov(a_U, a_A)] \quad (8)$$

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:

$$V_{P/E} = \frac{Var(a_P)+Cov(a_P,a_A)+Cov(a_P,a_U)}{Var(a_E)} \quad (9)$$

Similarly, the inter-country variance in a_C can be decomposed as:

$$Var(a_C) = [Var(a_P) + Cov(a_P, a_A) + Cov(a_P, a_U) + Cov(a_P, a_T)]$$

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

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

$$Cov(a_T, r_P) + Cov(a_T, a_A) + Cov(a_T, a_U)] \quad (10)$$

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

$$V_{P/C} = \frac{Var(a_P)+Cov(a_P,a_A)+Cov(a_P,a_U)+Cov(a_P,a_T)}{Var(a_C)} \quad 11$$

It may be noted that the contribution of inter-country variance in a_P to the inter-country variance in a_E or a_C 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

$$I_{P/E} = \frac{Var(a_P)+|Cov(a_P,a_A)|+|Cov(a_P,a_U)|}{S} \quad (12)$$

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

$$I_{P/C} = \frac{Var(a_P)+|Cov(a_P,a_A)|+|Cov(a_P,a_U)|+|Cov(a_P,a_T)|}{V} \quad (13)$$

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:

$$\begin{aligned} d_E = E_2 - E_1 &= (P_2 * A_2 * U_2) - (P_1 * A_1 * U_1) \\ &= \big((P_1 + d_P) * (A_1 + d_A) * (U_1 + d_U)\big) - (P_1 * A_1 * U_1) \\ &= (d_P * A_1 * U_1) + (P_1 * d_A * U_1) + (P_1 * A_1 * d_U) + (d_P * d_A * U_1) \\ &\quad + (d_P * A_1 * d_U) + (P_1 * d_A * d_U) + (d_P * d_A * d_U) \\ &= \partial P + \partial A + \partial U + \partial P \partial A + \partial P \partial U + \partial A \partial U + \partial P \partial A \partial U \end{aligned} \quad (14)$$

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

$$d_C = C_2 - C_1 = (P_2 * A_2 * U_2 * T_2) - (P_1 * A_1 * U_1 * T_1)$$

$$= \big((P_1 + d_P) * (A_1 + d_A) * (U_1 + d_U) * (T_1 + d_T)\big) - (P_1 * A_1 * U_1 * T_1)$$

$$= (d_P * A_1 * U_1 * T_1) + (P_1 * d_A * U_1 * T_1) + (P_1 * A_1 * d_U * T_1)$$

$$+ (P_1 * A_1 * U_1 * d_T) + (d_P * d_A * U_1 * T_1) + (d_P * A_1 * d_U * T_1)$$

$$+ (d_P * A_1 * U_1 * d_T) + (d_P * d_A * d_U * T_1) + (d_P * d_A * U_1 * d_T)$$

$$+ (d_P * A_1 * d_U * d_T) + (P_1 * d_A * d_U * d_T) + (d_P * d_A * d_U * d_T)$$

$$= \delta P + \delta A + \delta U + \delta T + \delta P\delta A + \delta P\delta U + \delta P\delta T + \delta A\delta U + \delta A\delta T + \delta U\delta T +$$

$$\delta P\delta A\delta U + \delta P\delta A\delta T + \delta P\delta U\delta T + \delta A\delta U\delta T + \delta P\delta A\delta U\delta T \qquad (15)$$

In order to estimate total effect of population change on the change in energy use and CO_2 emissions, it is necessary to distribute the interaction effect across interacting factors. Kim and Strobino (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 $\partial P\partial A$ in equation (14) may be estimated as

$$w_{P/A} = \frac{\left|\ln\left(\frac{P_2}{P_1}\right)\right|}{\left(\left|\ln\left(\frac{P_2}{P_1}\right)\right| + \left|\ln\left(\frac{A_2}{A_1}\right)\right|\right)} \qquad (16)$$

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

The change in energy use and CO_2 emissions between two points in time $t_2 > t_1$ may also be decomposed as

$$d_E = \frac{d_E}{a_E} a_E = \frac{d_E}{a_E} a_P + \frac{d_E}{a_E} a_A + \frac{d_E}{a_E} a_U \qquad (17)$$

and

$$d_C = \frac{d_C}{a_C} a_C = \frac{d_C}{a_C} a_P + \frac{d_C}{a_C} a_A + \frac{d_C}{a_C} a_U + \frac{d_C}{a_C} a_T \qquad (18)$$

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

$$P_E = \partial P + \omega_{P/A} \partial P \partial A + \omega_{P/U} \partial P \partial U + \omega_{P/AU} \partial P \partial A \partial U \qquad (19)$$

Similarly, the population effect of the change in CO_2 emissions can be estimated as

$$P_C = \delta P + \nu_{P/A} \delta P \delta A + \nu_{P/U} \delta P \delta U + \nu_{P/T} \delta P \delta T + \nu_{P/AU} \delta P \delta A \delta U + \nu_{P/AT} \delta P \delta A \delta T + \nu_{P/UT} \delta P \delta U \delta T + \nu_{P/AUT} \delta P \delta A \delta U \delta T \qquad (20)$$

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 miillion 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 CO_2 emissions changed four times. The annual percent change in global CO_2 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 CO_2 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 CO_2 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 CO_2 emissions varied widely across the 44 countries included in the present analysis (Table 3). The energy use and CO_2 emissions did not increase in all countries included in the present analysis. There are 11 countries where energy use decreased and 13 countries where CO_2 emissions decreased during the period under reference. The decrease in both energy use and CO_2 emissions has been the most rapid in Ukraine while the increase in both energy use and CO_2 emissions has been the most rapid in Malaysia. Among factors of energy use and CO_2 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 CO_2 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 CO_2 emissions. On the other hand, Brazil is the only country where all factors contributed to increase in energy use and CO_2 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 the 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 (PEC_E) as

$$PEC_E = \begin{cases} -\left(\frac{d_P}{d_U}\right) \; if\ P\ and\ U\ change\ in\ opposite\ directions \\ \left(\frac{d_P}{d_U}\right) \; if\ P\ and\ U\ change\ in\ the\ same\ direction \end{cases}$$

The PEC_E 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 CO_2 emissions (PEC_C) may be defined as

$$PEC_C = \begin{cases} -\left(\frac{d_P}{d_U + d_T}\right) \; if\ P\ and\ (U+T)\ change\ in\ opposite\ directions \\ \left(\frac{d_P}{d_U + d_T}\right) \; if\ P\ and\ (U+T)\ change\ in\ the\ same\ direction \end{cases}$$

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 CO_2 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 CO_2 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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Appendix

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

2011	13040	30699	7041194	14274	0.130	2.354
2012	13245	31184	7125828	14570	0.128	2.354
2013	13416	31748	7210582	14891	0.125	2.366
2014	13595	31811	7295291	15236	0.122	2.340
2015	13637	31759	7379797	15571	0.119	2.329
2016	13720	31704	7464022	15903	0.116	2.311
2017	13970	32099	7547859	16309	0.113	2.298
2018	14287	32805	7631091	16698	0.112	2.296
2019	14378	32741	7713468	16982	0.110	2.277

Table 2: Annual percent increase in energy use and CO_2 emissions in the world, 1990–2019.

Energy use		CO2 emissions		Population		Per capita real GDP		Energy intensity of GDP		Carbon intensity of energy use	
Period	Annual % increase	Period	Annual % increase	Period	Annual % increase	Period	Annual % increase	Period	Annual % increase	Period	Annual % increase
1990–2001	1.401	1990–1993	0.120	1990–1992	1.612	1990–1993	-0.077	1990–1996	-1.179	1990–1999	-0.198
2001–2006	3.289	1993–2002	1.579	1992–1996	1.453	1993–2003	2.035	1996–2001	-1.881	1999–2013	0.255
2006–2012	1.877	2002–2005	4.396	1996–2001	1.328	2003–2006	3.745	2001–2004			
2012–2019	1.184	2005–2012	2.219	2001–2010	1.246	2006–2019	2.163	2004–2007			
		2012–2019	0.683	2010–2015	1.187			2007–2010			
				2015–2019	1.109			2010–2019			
1990–2019	1.770	1990–2019	1.651	1990–2019	1.285	1990–2019	2.047	1990–2019			
Number of joinpoints											
3		4		5		3		5		2	

SOURCE: AUTHOR’S CALCULATIONS

Table 3: Energy use, CO_2 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**
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

Russia	879	779	2189	1754	147532	145872	20362	25450	0.293	0.210	2.491	2.251
Saudi Arabia	58	207	156	534	16234	34269	45603	51680	0.078	0.117	2.684	2.582
South Africa	90	135	252	447	36801	58558	10573	12837	0.231	0.180	2.808	3.301
South Korea	94	298	243	650	42918	51225	12157	39545	0.180	0.147	2.591	2.180
Spain	90	125	205	240	39203	46737	25500	38603	0.090	0.069	2.281	1.920
Sweden	47	47	53	39	8567	10036	32754	51311	0.168	0.091	1.113	0.835
Taiwan	48	110	115	280	20479	23774	8173	24389	0.285	0.189	2.412	2.555
Thailand	42	142	81	271	56558	69626	7106	18381	0.104	0.111	1.929	1.905
Turkey	51	147	133	377	53922	83430	12532	27754	0.076	0.063	2.576	2.563
Ukraine	252	89	690	177	51463	43994	11268	8689	0.435	0.232	2.739	1.990
United Arab Emirates	20	69	52	199	1828	9771	119987	71246	0.093	0.100	2.553	2.868
United Kingdom	206	171	556	346	57134	67530	28945	43190	0.125	0.059	2.700	2.023
United States	1910	2213	4866	4920	252120	329065	39199	60544	0.193	0.111	2.548	2.223
Uzbekistan	46	37	116	89	20398	32982	3298	7299	0.689	0.152	2.509	2.440
Venezuela	40	39	94	87	19633	28516	15613	6608	0.129	0.205	2.368	2.237

Table 4: Decomposition of the inter-country variance in the rate of change in energy use and CO_2 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			
CO_2 emissions (C)					
Var (*C*)		0.475	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*					
	Var (*A*)	0.249	0.133	28.08	39.86
	Cov (*AP*)	-0.032			
	Cov (*AU*)	-0.106			
	Cov (*AT*)	0.022			

Table 4: Continued

Particulars	Variance and covariance		Variance explained: Total	Variance explained: Percent	Relative importance
Var (*C*) 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 (*C*) 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				CO_2 emissions			
			Total	%			Total	%
Change attributed to energy intensity of GDP			-5556	-98.83			-12659	-101.84
Direct		-3237				-7508		
Indirect		-2319				-5151		
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				
			Direct	Indirect	Decomposition of indirect effect		
					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

Iran	188.271	53.197	32.638	20.559	7.276	10.121	3.162
Italy	2.275	9.008	9.008	0.000	0.407	-0.371	-0.036
Japan	-19.416	8.348	8.329	0.019	0.166	-0.126	-0.021
Kazakhstan	15.142	10.043	9.717	0.326	1.451	-0.751	-0.375
Kuwait	26.406	14.307	9.180	5.126	3.764	0.948	0.414
Malaysia	71.623	24.345	16.380	7.965	10.350	-1.401	-0.984
Mexico	53.846	64.100	64.287	-0.187	12.312	-10.142	-2.358
Netherlands	4.574	9.668	9.475	0.193	1.249	-0.783	-0.273
New Zealand	6.507	5.813	5.568	0.244	1.457	-0.870	-0.342
Nigeria	101.351	82.049	73.785	8.264	26.398	-12.969	-5.166
Norway	6.139	5.767	5.614	0.153	1.060	-0.688	-0.218
Poland	-0.340	-0.197	-0.197	0.000	-0.001	0.000	0.000
Portugal	5.324	0.566	0.561	0.005	0.021	-0.014	-0.002
Romania	-28.185	-11.649	-10.882	-0.767	-2.663	1.040	0.857
Russia	-99.337	-9.896	-9.883	-0.013	-0.119	0.092	0.014
Saudi Arabia	148.933	94.900	64.439	30.461	7.355	20.628	2.478
South Africa	45.590	52.188	53.043	-0.855	8.011	-7.589	-1.277
South Korea	204.168	21.129	18.187	2.941	5.344	-1.553	-0.850
Spain	34.707	17.932	17.315	0.617	2.649	-1.607	-0.425
Sweden	-0.132	8.255	8.093	0.162	1.195	-0.761	-0.272

Table 6: Continued

Country	Increase in energy use during 1990–2015	Increase in energy use attributed to increase in population	Decomposition of population effect				
			Direct	Indirect	Decomposition of indirect effect		
					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 CO_2 emissions (Mt) in 44 countries, 1990–2019

Country	Increase in CO_2 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 CO2 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	0.001	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

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

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