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The relationship between population and the environment and its impact on sustainable development in Egypt using a multi-equation model

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Abstract The relationship between population and the environment is a significant issue due to its impact on chances for achieving sustainable development, especially in developing countries. Previous studies on this relationship have primarily focused on the impact of population growth on the environment, while the impact of the environment on population has received less attention, where most of these studies have used single-equation models (SEM) in their analysis. In order to capture the interrelationship between population growth and the environment, and both its direct and indirect effects on the potential for achieving sustainable development, SEM may not be appropriate. This paper takes a step forward in providing such empirical evidence, by developing a multi-equation model based on the recursive equation system in order to empirically examine the relationship between population growth and the environment in terms of air pollution represented by increased CO_2 emissions, health level represented by the mortality and morbidity due to air pollution, and labour productivity represented by GDP per hour worked, and using a time series data set for Egypt during the period of 1950–2010. Quantitatively, the current study finds that (1) In Egypt, a 1% increase in population raises the CO_2 emissions by 2.4%. (2) An increase in CO_2 emissions by 1% is associated with an increase in deaths due to outdoor air pollution (respiratory and cardiovascular diseases) by 2.5%. (3) Poor health due to air pollution leads to a decrease in labour productivity by 1.58%. (4) The impact of population growth on chances for sustainable development depends on how much the rise in air pollution decreases labour productivity through raising the rate of morbidity. (5) Even when rapid population growth rate plays a minor role in creating a specific problem, such as its indirect negative impact on labour productivity and thus economic growth, population management policies may still constitute a viable measure for dealing with that problem, especially with respect to policy intervention cost. The study argues that population growth in Egypt negatively affects the state's ability to achieve sustainable development via its negative impact on the environment. Environmental degradation in turn

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leads to adverse effects on population, particularly with regard to public health. These negative effects on health lead to lower labour productivity, and thus hinder the state's ability to sustain development.

Keywords Egypt sustainable development · Population growth · CO_2 emissions · Health · Labour productivity · Recursive equation model multi-equation model · Egypt · Multi-equation model

1 Introduction

The Rio Declaration, agreed at the United Nations Conference on Sustainable Development (UNCSD) held in 1992 at Rio de Janeiro, Brazil, and the Program of Action, agreed at the International Conference on Population and Development (ICPD) held in 1994 in Cairo, Egypt, both designate humans as the centre of sustainable development:

> "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature" Rio Declaration, Principle 1 (UN 1992).

Sustainable development as a mean to ensure human well-being, which is equitably shared by the present and the future generations, requires that the interrelationships between population, the environment, and economic development should be completely recognized, adequately and harmoniously managed, and brought into a dynamic balance, especially in developing countries. Therefore, a clear understanding of the relationship between human and environmental resources, along with determining the significance of the problems associated with them, should become a priority for policymakers, and for development programs which aim at achieving sustainable development.

The vast majority of empirical studies which dealt with the relationship between population and the environment have concentrated on the impact of demographic factors, such as population growth, urbanization, migration from rural to urban, and changes in age and gender structures, on the environment. There is significant evidence that the relationship between population and the environment is bidirectional. The first direction is the impact of demographic factors on the environment which causes an overuse of natural resources and increases pollution.

The second direction is the effect of environmental factors on the population through the negative impact of pollution on health and labour productivity, which are the key dimensions of economic performance, and are the essential drivers of changes in living standards. Nevertheless, the vast majority of studies which dealt with the relationship between population and the environment have concentrated on the first direction and ignored the second.

Single-Equation Models (SEM) has often been used in most of the population–environment literature in order to describe the impact of population growth on the environment. The description and assessment of the relationship between population and the environment using SEM exhibits many shortcomings, because this type of models usually explains just one aspect of that relationship (Attia 2005). As the relationship between population and the environment is complicated and overlapped to a great extent, *Multi-Equation Models* (MEM) may be more appropriate to describe and analyse this type of phenomenon, because it takes into account the interdependence relations between variables. Therefore, in order to empirically examine the relationship and the causal dependence between population and the environment and its impact on chances for sustainable development in Egypt, a MEM based on the *Recursive Equation System* (RES) for the environmental, social, and economic dimensions of sustainable development needs to be developed.

This study mainly focuses on a number of selected indicators which represent the fundamental aspects of sustainable development. These are believed to be both causally related, and at the same time represent, serious problems to achieving sustainable development in developing countries in general and in Egypt in particular. The idea is based on thinking across different sectors and providing a path analysis of the causal chains and linkages between the three main pillars of sustainability.

The first pillar is the environmental dimension. The selected indicators to express this dimension are climate change and local air pollution, which together represent a main concern in Egypt. These are completely caused by human activities and can be linked directly to population size and growth rate. The second pillar is the social dimension, in terms of population health status. The indicator selected to refer to this dimension is population health problems related to climate change and local air pollution, where air pollution-related diseases affect a considerable segment of the Egyptian society.

The economic dimension is the third pillar, for which labour productivity is selected as an indicator of economic performance. Low labour productivity in Egypt is a major problem for the economy, and while this problem can be attributed to many reasons, the population health status is considered to be a major factor in causing it, especially with the presence of a large proportion of outdoor workers who are more vulnerable to the impact of air pollution and climate change.

Accordingly, the suggested system includes three structural equations developed to describe and analyse the complicated and overlapped relationship between sustainability dimensions, and to take into consideration the interdependence relations between variables. The system consists of environmental, health, and labour productivity functions. The empirical analysis is based on a time series data set for Egypt during the period of 1960–2010.

1.1 Egypt background

As shown in Fig. 1, Egypt occupies the north-eastern corner of Africa. It generally has hot desert climate and little rain. The River Nile is the main source of water in Egypt, and it provides over 95% of the country's water needs. The delta and the narrow valley of the Nile represent 5.5% of the area of Egypt, and about 95% of Egypt's population and agriculture are concentrated in that area. The agricultural land represents about 3.7% of total land area, and almost 50% of the population depends on agricultural activities for employment and generating income. The primary energy resources such as oil, natural gas, coal and hydropower are limited (EEAA 1999).

1.1.1 Population

Egypt is the second largest African country with respect to population size. The population of Egypt rose from 27 million in 1960 to more than 91.5 million in 2015 (World Bank 2015a). The annual growth rate for the Egyptian population is predicted to remain over

Fig. 1 Map of the Arab Republic of Egypt. *Source*: Egyptian Environmental Affairs Agency (1999)

2%[1] until 2040, where the population is estimated to reach 116 million (UN 2015). Nearly 43.6% of the total population lives in urban areas, where most of them live under crowded conditions (UNDP 2013). Rural population, as a percentage of total population, remained around 56% during the period 1990–2010 (UN 2015). Egypt's population is very large in relation to the country's limited natural resources, and the rapid population growth has put a significant pressure on the natural resources and the environment, due to the increased production required for coping with the basic needs and the creation of jobs for the population.

Egypt is a unique country in terms of its population distribution, which is extremely uneven (El-Kholei 2005), see Fig. 2. The main metropolitan areas in Egypt are Cairo and Alexandria. Cairo is one of the most overcrowded cities in the world. In 2012, it had an estimated population of 17.8 million and an average population density of 15,000 per Km^2. In some areas of Cairo and Alexandria, the population density exceeds 100,000 persons per square kilometer (WHO 2010a).

Overall, it is estimated that approximately 25% of the total population of Egypt live in slums[2] under poor living conditions and inappropriate housing. The number of slum areas in Egypt is estimated to be around 1221 areas,[3] spread in 24 governorates and inhabited by more than 20 million people. The largest slum areas in Egypt are concentrated in Cairo governorate, which alone has more than 81 slum areas, providing home to nearly 8 million

[1] The current annual growth rate is about 2.2% (UN 2015).

[2] Unplanned areas in Egypt, including slums, represent about 95% of urban areas in Egyptian villages and 37.5% of urban areas in Egyptian cities (UN 2015).

[3] Some other studies indicated that the number of slum areas in Egypt is 1105, which represent approximately 30% of residential areas, and there are approximately 16 million people who live in Egypt's slums (WHO 2010a).

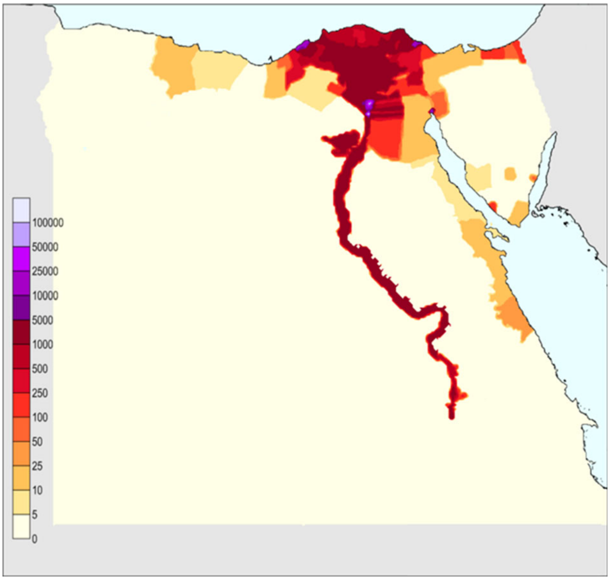


Fig. 2 Egyptian population density (person per km^2). *Source*: Abuo-El-khir (2012)

people (UNFPA 2008). The deteriorating environmental conditions prevailing in these areas pose many health risks to those people, where the spread of many diseases is linked to environmental degradation.

1.1.2 Climate change and air pollution

Air pollution in Egypt, especially in Cairo and Alexandria, has been a problem for several years. The main air pollutants in urban and industrial areas are lead, suspended particulate matter (SPM), and carbon dioxide (WHO 2010a). Egypt globally ranks 31st in terms of its contribution towards total greenhouse gas (GHG) emissions, and is classified as one of the top-level countries in terms of growth in CO_2 emissions (Hassan 2013). The average annual increase in CO_2 emissions estimated to be 9.6% (UNDP 2015). The total GHG emissions were equal to 318.2 million tones of equivalent CO_2 in 2012, where CO_2 emissions represent 72% of these. The main source of GHG emissions is the energy sector because Egypt is 97% dependent on fossil fuels. The estimated average for annual growth of per capita carbon dioxide emissions was nearly 4% during the period of 1970–2008 (UNDP 2013). Although Egypt's contribution to the global GHG emissions is relatively limited (about 0.6%[4] of total global GHG), its vulnerability to the effects of climate change is too high (Smith et al. 2013; Abou-El-Naga 2015).

1.1.3 Health

Climate change and air pollution are strongly linked to the health sector (Handoussa 2010), as climate change has been proven to have direct and indirect negative impacts on public

[4] According to Hassan (2013) and Handoussa (2010), this number is estimated to be 7 and 5.7%, respectively.

health in Egypt (UN 2015). The Egyptian Environmental Affairs Agency (EEAA) indicted that cardiovascular and respiratory disease are a major concern in Egypt, and that the high air pollution levels in the country may be its major cause (EEAA 2010). Moreover, the current increasing temperatures and drier conditions could increase pollution levels even more in the future.

World Health Organization (WHO) (2010a) reported that the total burden of disease in 2008 was 172 disability-adjusted life years (DALYs[5]) lost per 1000 persons. The disease groups most contributing to the burden of disease are cardiovascular diseases (19.5%), digestive diseases (10%), injuries (8%), and chronic respiratory diseases (6.6%). The WHO reports indicate that there was a substantial increase in the contribution of cardiovascular and respiratory infectious diseases in the mortality burden during the last few decades. The combined mortality rate due to cardiovascular and respiratory diseases was estimated to be 406 per 1000 death in 2008 (UNDP 2013). Regarding the burden of disability, indictors illustrated that chronic respiratory diseases and cardiovascular diseases are among the main causes of disability in Egypt, accounting for 6.9 and 5.6%, respectively, of the burden of disability (WHO 2010a). It is estimated that the annual economic loss due to the impact of air pollution on health ranging from 1.1 to 3.2% of the Egyptian gross domestic product (GDP) (World Bank 2002).

1.1.4 Economy

Egypt is one of the lower middle-income countries. The main sources of income are tourism, remittances from Egyptians working abroad and revenues from the Suez Canal. Its economy had a fluctuating growth rate since 1960, increasing to 14% in 1977 then falling to 1.8% in 2011. The estimated Egyptian GDP in 2015 was about 331 billion US$ (World Bank 2015a). Population under national poverty line represented 22% of the total population in 2012. Adult literacy rate was 72% in 2010, with a noted gender imbalance where only 38% of literate adults are females, compared to 62% males. The Egyptian unemployment rate was estimated to be 13% of total labour force in 2012 (UNDP 2013).

Labour productivity in Egypt is very low compared to the specific number of hours of work according to the International Labour Organization (ILO) standards (8 h per day). Low levels of labour productivity represent one of the main obstacles facing the Egyptian labour market, along with increasing unemployment rates among highly educated youth, growing trends of informality, and scarcity of skilled workers (Amin 2014). In addition, the high level of sickness absence, especially in the industrial sector, represents a serious problem to the Egyptian economy.

The WHO indicated that outdoor air pollution in Egypt can have direct and sometimes severe consequences for health, and hence labour productivity (WHO 2015). Under the current level of high emissions, labour productivity is projected to decline significantly due to heat stress, as about 6% of annual daily work hours are projected to be lost by workers in agricultural and industrial sectors, which employ more than 50% of the Egyptian labour force.

The World Bank indicated that in Egypt, working time for people suffering from chronic diseases, like heart and cardiovascular diseases, chronic respiratory conditions, cancer, and other non-communicable diseases is reduced by 22 h per week on average, and

[5] DALYs for a disease or health condition are calculated as the sum of the years of life lost (YLL) due to premature mortality in the population and the years lost due to disability (YLD) for people living with the health condition or its consequences.

that the probability of employing those people is 25% lower than average. This implies an overall production loss of about 12% of the Egyptian's GDP due to lost employment and reduced numbers of hours worked by those reporting chronic conditions (World Bank 2011).

1.1.5 Sustainable development

In 2008, Egypt has issued its National Sustainable Development Strategy (NSDS). The strategy addressed many priority areas and challenges related to economic, social, institutional, and environmental aspects of the society. The primary focus of the strategy was on industrial development, solid waste management, urban development, and transportation. In 2015, Egypt launched a sustainable development strategy called 2030 Vision which is based on 12 pillars. The main focus of that strategy is on fostering economic growth through expanding the role of private sector (World Bank 2015b), attracting large domestic and foreign investments in order to provide more jobs and improve living standards to all Egyptians (Egypt's Sustainable Development Strategy: 2030 Vision 2015). Once again, Egypt's sustainable development strategy reflects the isolation of environmental and social issues from the mainstream of development planning and sustainability efforts.

Given Egypt's growing population, its limited fertile land, and its large area of desert, and the concentration of its population in the narrow Nile valley and northern coastal zones, the potential social and economic impact of environmental degradation, especially air pollution, could be devastating for the country's future. Therefore, Egypt seriously needs to follow a growth model in which economic and social in addition to environmental situations are taken into consideration carefully and equally, thus improving people's living standards today and in the future.

Therefore, the objectives of this study can be summarized in attempting to answer the following questions*:* "How does population growth affect the environment in Egypt? To what extent does air pollution threaten the public health in Egypt? To what extent does poor health affect labour productivity in Egypt? How to achieve sustainable development in Egypt? And what are the methods and policies that the State must follow in order to sustain development?"

This paper is organized as follows. In the following Sects. 2 and 3, I briefly review the literature and empirical work on the relationship between population and the environment, with special concentration on the impact of population growth on air pollution and climate change in terms of carbon dioxide emissions, and the role of carbon dioxide in deteriorating public health and labour productivity. Then, the model specifications, data sources, and variables are discussed in the Sect. 4. The major findings of the study are reported in the Sect. 5. Finally, I conclude with some thoughts and implications relevant to policy making in the Sect. 6.

2 Theoretical perspectives

The impact of population pressure on environmental quality can be traced back to the early argument on the relationship between population and natural resources. In 1798, *Malthus* argued that population expanded geometrically, while the subsistence level of food production increases only at an arithmetic rate. His predictions indicated that if mankind was not exposed to preventive checks, then the potential growth in food supply could not keep up with that of the population, and finally population growth would be restricted by welfare checks, mainly poverty, disease, famine, and war.

The Neo-Malthusian school elaborates on the same idea, by arguing that in the long run, an exponential growth of population owing to unrestrained fertility will outpace the natural resources, thus leading to ecological catastrophe (De Sherbinin et al. 2007). Another example of this line of thinking is the Club of Rome's *Limits to Growth* scenarios established by Meadows (Meadows et al. 1972). According to this school, industrialization and rapid population growth will lead in the long run to food production crises and environmental pollution which has adverse health effects, and thus population collapse (Atkinson et al. 2007).

In contrast to Neo-Malthusianism, *Boserup* in 1965 introduced an optimistic view of the impact of population growth on the environment. Contemplating the agricultural and industrial revolutions, she proposed that high population growth rate and densities are inducing technological development and innovation, especially in agricultural activities, thus leading to increased resources utilization and production (Boserup 1965, 1981).

Julian Simon in his book *The Ultimate Resource* further extended the Boserupian view. He proposed the *Theory of Cornucopian* in 1981, where he indicated that the increase in population leads to many positive effects like stimulating inventiveness not only in the field of agriculture activities but also in all economic and social aspects, thus enhancing more production and investment and reducing negative environmental side effects (UN 2001b).

Over the past few decades, the work on the relationship between population and the environment has witnessed a substantial development. Theoretical perspectives and methodological approaches have expanded to include many aspects and interactions between demographic, economic, social, and environmental factors. This germinate interdisciplinary field of study is known as the *Population–Environment (P-E) Analysis* (Hummal et al. 2009). In P-E literature, the concept of *Environmental Hazard* is divided into two main categories, natural hazards related to the depletion and availability of both renewable and non-renewable natural resources, and man-made hazards such as air pollution and soil contamination (Hummal et al. 2009). P-E theories include a wide range of analytical methods for dealing with these environmental problems, which differ according to their specific natures and study purposes. These range from attempting to obtain a general understanding of systems' behaviour through building simple conceptual models, to providing realistic evaluations of specific policies by developing more comprehensive models (Costanza and Ruth 1998).

Linear perspectives represented by the Malthusian and Boserupian theories are mostly considered to be the corner stones of P-E analysis, upon which most of the methodological approaches in this field are built, along with the *Multiplicative approaches,*[6] especially the *Impact, Population, Affluence, Technology* (IPAT) model, and the *Stochastic Impacts by Regression on Population, Affluence and Technology* (STIRPAT) model. The *Carrying Capacity* and *Ecological Footprint* concepts are commonly used in P-E literatures in order to analyse important issues such as population dynamics, human demand of resources, ecosystems' maximal load, and the optimal way of using natural resources. The *Mediating Variable* approach is another method for studying the relationship between population and the environment. It emphasizes that the relationship between population dynamics and the environment is mediated by a number of factors such as macroeconomic policies, globalization, and the institutions' dominant access to resources (Glaser et al. 2012).

[6] *Multiplicative* approaches will be discussed later in more detail.

On the microlevel, the *Sustainable Livelihoods* approach (SL) focuses on household dynamics and social networks, and the recursive nature of population–environment relationships, whereby the mutual feedbacks among population growth, poverty, and environmental degradation constitute a closely linked loop expressed as a *Vicious Circle Model* (VCM) (Bremner et al. 2010). Also, the *Social–Ecological* perspective tries to examine the relationships between people and their particular natural and social environments explicitly. This dynamic approach takes into account population changes and the relevant social and environmental changes, and their mutual influences and feedback loops in both directions (Hummal et al. 2009).

System Theoretical approaches deal with the environment and population as interacting systems. The main focus of these approaches is the reciprocal impacts of environmental and social changes. Models in P-E analysis based on these approaches connect demographic parameters such as gender and age structures, and migration to other socio-economic parameters such as education and equality, and all of these variables, in turn, are linked to some other factors like land and soil degradation, food production, and distribution. Examples of these are the *Population–Development–Environment* (PDE) model, and the *Population–Environment–Development–Agriculture* (PEDA) model (Glaser et al. 2012).

Several studies dealing with the relationship between population dynamics and the environment have employed the *Predator–Prey* model or *Lotka–Volterra* relation (Lotka 1925; Volterra 1926). This *System Dynamics* model is well known in biological, ecological, and environmental studies and has been widely used in many other fields, such as economics and demography (Puliafito et al. 2008). *Economic–Ecological* models based on the predator–prey model and system dynamics, such as the *Human And Nature DYnamical* (HANDY) model, or the *Brander–Taylor* (BT) model and its derivatives, are used to explore the causal loops and sophisticated feedbacks between many variables such as population, economic growth, capital, labour, and natural resources availability (Brander and Taylor 1998; Uehara 2012; Motesharrei et al. 2014; Uehara et al. 2016).

Hereby, the *Multiplicative approaches* will be addressed in some detail, as it represents the main concern of the current work. In these approaches, population is linked to the environment through two main factors, namely economic activity and technological progress (UN 2001a). One of the best examples of this approach is the well-known IPAT model introduced by Ehrlich and Holdren. The IPAT identity is expressed by the following equation (Ehrlich and Holdren 1971):

$$\text{Impact} = \text{Population} \times \text{Affluence} \times \text{Technology} \quad \text{or } I = P \times A \times T$$

where (I) refers to the human impact on the environment, which is equal to the product of population size (P), affluence (A) in terms of per capita income, and technology used to produce one unit of affluence (T) which indicates the impact of technology on the environment. This model has been criticized for many reasons (Bernstam 1991; Dietz and Rosa 1994), most notably are the disregard of the interactions among variables on the right-hand side of the equation, and the omission of important variables such as social factors (Cole and Neumayer 2004), in addition to the inability of IPAT model to accurately determine the relative contributions of the factors responsible for environmental degradation.

There have been several efforts to further improve and revise the IPAT model to consider those criticisms. Preston suggested a refinement of the original IPAT model by using an *Additive Approach* to explore the differences in the growth rates of I, P, A, and T

over different regions. The proposed relationship for growth rates takes the following formula (Preston 1996):

$$\sigma_I^2 = \sigma_P^2 + \sigma_A^2 + \sigma_T^2 + 2\mathrm{COV}_{PA} + 2\mathrm{COV}_{PT} + 2\mathrm{COV}_{AT}$$

According to this model, the sum of $\left(\sigma_P^2 + 2\mathrm{COV}_{PA} + 2\mathrm{COV}_{PT}\right)$ represents the relative contribution of changes in the population growth rate to environmental degradation, where the covariance indicates the interaction effects.

A combination between the IPAT identity and the ecological footprint concept resulted in the so-called STIRPAT model. This model is a random version of the IPAT model, which takes the following formula (Dietz and Rosa 1997; Dietz et al. 2007):

$$I = aP^bA^ce$$

where (b) and (c) are, respectively, the carbon emissions[7] elasticity of population and affluence, (e) is an error term referring to all the other variables not included in the model specially technology. The main advantage of this model is that it can be examined using *nonparametric* regression methods, which does not require an a priori assumption about the functional forms connecting population and affluence to the environmental impact. Also, it avoids several difficulties in finding an appropriate measure of technology (Puliafito et al. 2008). Many studies conclude that the best fit to the STIRPAT model is acquired from using a log-polynomial formula with significant linear and quadratic terms in the population variable, and significant linear, quadratic, and cubic terms in the affluence variable (Gansa and Jöst 2005).

Generally, theoretical and empirical works aiming at exploring the relationship between population and the environment are based on discussing four trends: population dynamics, environmental dynamics, the effects of population on the environment, and the impact of environment on population. Nevertheless, the main focus of the vast majority of this research was the first three trends while neglecting the fourth one.

3 Brief review of empirical work

In this section, results of some empirical studies will be reviewed. These will be divided into two main points: the impact of population growth on the environment in terms of air pollution represented by CO_2 emissions, and the impact of the environmental degradation, represented by air pollution, on population in terms of public health and labour productivity:

3.1 The impact of population growth on the environment in terms of air pollution represented by CO_2 emissions

Engelman (1994) and Knapp and Mookerjee (1996) emphasized that population growth has been a major force in driving up global CO_2 emissions over recent decades. Knapp and Mookerjee employed the Granger causality test, and used annual data during the time period 1880–1989, as well as comprehensive models (e.g. error correction and co-integration models). They concluded that carbon dioxide emissions can be relied upon in predicting the rates of population growth, while the lack of integration between carbon

[7] Or any other type of environmental degradation.

dioxide emissions and population growth indicates that the control of population growth is not the only factor in reducing future CO_2 emissions.

Dietz and Rosa (1997, 1998) found that the most populous countries had an impact on CO_2 emissions greater than unity, where an increase of 1% in population was associated with an increase of 1.15% in emissions. This finding supports the Malthusian argument. Meyerson (1998) also emphasized that the global increase in carbon emissions has been closely correlated with population growth over about a 25-year period. Shi (2001) applied Dietz and Rosa's stochastic model, and used a data set of 93 countries for the period of 1975–1996. The results of his study showed that on the average, an increase of 1% in population is associated with an increase of about 1.28% in carbon dioxide emissions. Also, his estimations indicated that about half of the increase in emissions by 2025 would be attributed to future population growth alone.

Shi (2003) found that the impact of population on emissions is more than unity, where a 1% increase in population raises emissions by 1.42%. This proportion is larger than that estimated by Dietz and Rosa (1997) in their cross-sectional data analysis. He indicated that the impact of population growth on emissions is more noticeable in developing countries than developed countries. He illustrated that the estimated elasticity of emissions with respect to population growth is about 2 in developing countries, whereas in developed countries it is less than 1. These findings provide support for the Boserupian point of view that, in the long run, technological change responds to environmental pressures. Cole and Neumayer (2004) also used the logarithmic formula of the IPAT model in their study, their findings, in agreement with the study by Dietz and Rosa (1997), suggested that the increase in population growth rate leads to an increase in emissions of carbon dioxide roughly by the same percentage. Additional factors were found to cause further increases in emissions, namely increasing rate of urban growth, and the decline in the average household size.

Hamilton and Turton (1999) and Hamilton (2002) discussed the relationship between population policy and environmental degradation. They concluded that the Australian population policies, especially the policy of encouraging immigration to Australia, had a significant impact on the increase in greenhouse gases emissions in Australia, compared to other members in the Organization for Economic Co-operation and Development (OECD), where it was argued that a large part of population growth in Australia can be attributed to immigration.

Gansa and Jöst (2005) suggested a model containing two structural equations. The first equation takes into account the determinants of population growth, such as the rate of growth in per capita income, the social status of women, and literacy. The second consists of a logarithmic-linear form of the IPAT model. The study emphasized that this formula is more appropriate as a starting point than the IPAT identity and Preston's model for empirical work aiming at measuring the quantitative impact of population growth on the environment.

De Sherbinin and Curran (2004) suggested that change in household numbers is a better predictor of greenhouse gas emissions than the overall population growth, because the actual consumption of energy is determined by the number of families, rather than the overall population. Furthermore, actual energy needs per household do not decrease in proportion to the size of the household. It is worth noticing that the use of household numbers as a unit of analysis by De Sherbinin and Curran indicates a shift in the population–environment literature from analysis at the macrolevel to analysis at the microlevel.

3.2 The impact of the environmental degradation in terms of air pollution on population

This section is divided into two main points: the impact of air pollution in terms of CO_2 emissions on health status, and the adverse effects of poor health on labour productivity.

With respect to the impact of air pollution on the population's health, the WHO (1997) indicates that approximately 23% of the total Global Burden of Disease (GBD) can be traced directly to deterioration of the environment. The UN (2001c) reports that air pollution in urban areas is associated with excess morbidity and mortality, where overcrowding and inadequate housing contribute to respiratory diseases. UNFPA (2001) and Von Hilderbrand (2009) indicated that air pollution is associated with respiratory and cardiopulmonary diseases and death. The UNFPA reported that air pollution, both outdoors and indoors, kills between 2.7 and 3 million people every year, about 90% of them in developing countries. According to that report, outdoor air pollution harms more than 1.1 billion people around the world, and directly causes death to about half a million people per year,[8] 30% of them are in developed countries' cities. Indoor air pollution affects about 2.5 billion people, most of them were women and girls, and is responsible for killing more than 2.2 million persons each year, where over 98% of them are in developing countries.

The United Nations (2001b) indicated that most modern environmental threats to health arise from the degradation of air quality, especially in urban regions, where transportation, energy generation, and energy-intensive industrial operations are concentrated. The report illustrated that air pollutants, including gases such as carbon dioxide, nitrogen dioxide, and sulphur dioxide, along with suspended particulate matter (SPM), have negative effects on health. Sulphur dioxide, for example, can impair the immunity of the lungs, thus causing asthma or other acute respiratory distress. The WHO estimated that air pollution by SPM is responsible for about 3 million deaths each year. Lead, which is a component of SPM, is associated with reduced intelligence, impaired mental development, reduced birth weight, and disturbances of the nervous system. Aluminium released into air as a result of industrial processes can be toxic to the nervous system, causing tremor, impaired balance, reduced memory recall, and slow speed of cognitive functions.

The WHO (2009) illustrated that an increased level of heat exposure can worsen the clinical condition of people with pre-existing chronic diseases and mental health problems, especially those who suffer from heart, lung, blood vessel diseases, and cancers. The report also pointed out that by year 2020, chronic diseases and mental health problems caused by climate change and air pollution are expected to rank at the top in the calculation of the GBD.

According to the report, high temperatures associated with high air humidity will lead to dehydration which can cause chronic kidney diseases and adverse effects on the cardiovascular system. The report illustrated that there are five pathways through which climate change affects human health. The first pathway is the direct exposure to heat, which leads to adverse effects on the cardiovascular system. The acute effects primarily impact the elderly, infants, children, and people with certain pre-existing diseases. Heat exhaustion leads to reductions in work ability and thus lowers productivity, especially among outdoor workers (WHO 2010b).

[8] Global estimates of mortality due to outdoor air pollution range between 200 and 570 thousands, which represent about 0.4–1.1% of total annual deaths, and indoor air pollution has been proved to be more lethal than outdoor air pollution (Smith and Mehta 2003).

The second pathway is the exposure to air pollution which leads to various respiratory diseases. Exposure to malnutrition is the third pathway, where climate change could lead to drought, thus decreasing food production, especially in low-income countries. The fourth pathway is exposure to extreme weather and sea-level rise. Finally, infectious or vector-borne diseases are the fifth pathway, where the clinical condition of people who suffer from infectious diseases may become worse in high temperatures. These diseases may also affect the same person many times during his life, leading to a reduction in his ability to work.

Communicable diseases spread faster under rising temperatures caused by global warming and climate change. The WHO (2008) illustrated that high temperature has increased the transmission of malaria in many regions. Malaria is responsible for killing nearly 1 million people per year, especially young children in Africa, and almost 300 million acute illnesses. Dengue fever has spread rapidly in recent years and is now endemic in over 100 countries. It is estimated that some 2.5 billion people are currently at risk of infection. UN (2001b) indicated that the tropical cluster of diseases like schistosomiasis, Chagas disease, leishmaniasis, and lymphatic filariasis are transmitted by vectors that benefit from tropical conditions, such as high humidity and temperature. These diseases are responsible for low levels of mortality worldwide, but for a high level of disability, especially in the less developed countries. Various studies illustrated that GHG emissions resulting from human activities are the main cause of the ongoing climate change, and that carbon dioxide represents 75% of those emissions.

United Nations (2001b) emphasized that economic and social factors such as education and income, which largely determine the individual's residence, and his ability to control the quality of the environment in which he lives, are also important determinants of the individual health status. Also, high population growth, associated with poverty in developing countries, has put continuous pressures on the natural resources and environment. These pressures, in turn, contributed to the growth of urban slums and increased opportunities for disease transmission. Thus, the high rates of emergence and the return of some formerly eradicated diseases in developing countries have been driven by population growth and density and by increased immigration from the countryside to cities.

WHO (2009) also emphasized that the vast majority of people who migrate from rural to urban areas in developing countries end up living in slums, where heat exposure due to climate change, air and water pollution, and waste are much greater than in other parts of the city. There is an increasing trend of slums prevalence in cities, where the data indicate that about 60% of the urban populations in low-income countries live in slums. Some other studies estimated this figure to be 75% of the total population of urban areas in developing countries (Bloom and Khanna 2007).

As population growth has proved to be one of the major causes of air pollution, and air pollution has proved to have significant negative effects on human health, this suggests a model of reciprocal causality with a negative feedback loop, where population growth causes air pollution, and air pollution causes reductions in the population growth rate. In this situation, the feedback effect is very weak, as numerous studies confirmed that air pollution is responsible for a low proportion of total deaths, and even if air pollution has a negative impact on fertility rates and reproductive health, there is little evidence that the overall levels of fertility have been affected (UN 2001b; Cramer 2002). Other types of effects of air pollution on population may be more important, such as disability and ill health. In developing countries, air pollution has a much larger impact on disability than on mortality.

The European Environment Agency (2013) indicated that during the past few decades, the global burden of diseases has shifted away from communicable to non-communicable diseases, and from premature death to years lived with disability. Disability resulting from non-communicable diseases has many social and economic consequences, as it drives up health care costs, reduces labour productivity, thus hindering economic growth, in addition to human suffering.

With respect to the impact of health on labour productivity, Krugman (1997) illustrated the importance of labour productivity as one of the most important indicator of economic performance, he stated that: "Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker."

Fogel (1994) demonstrated that about 30% of the growth in per capita income in England since 1790 can be traced to health and nutritional improvements alone. This estimate is similar to those found in a number of cross-country studies dealing with the impact of health on productivity, where most of them used data for the last 50 years (WHO on Health and Economic Productivity 1999; Rivera and Currais 1999b). All these studies suggested that health may be one of the most important determinants of productivity, especially in developing countries.

Knowles and Owen (1997) and Rivera and Currais (1999a) found that improvements in public health can explain between 21 and 47.5% of the growth of GDP per worker over the last 30 years. They stressed the importance of understanding the empirical relationship between labour market outcomes and health, especially in designing and evaluating the cost-effectiveness of policy interventions regarding prevention and cure of disease (Currie and Madrian 1999).

Stansfeld et al. (1995) illustrated that investments in health improvements reduce sickness absence, consequently increasing productivity. His view is based on the assumption that the main reason for sickness absence is health problems, such as acute conditions related to respiratory and gastrointestinal systems. Also, Bloom et al. (2001) emphasized that a healthy labour force usually has more physical and mental energy, and thus more productivity. This study suggested four pathways by which health status can affect labour productivity, where the most important pathway is the positive impact of health improvements on sickness absence.

Tompa (2002) indicated two levels on which health status can affect labour productivity. On the individual level, a better health status can increase the yearly output through decreased morbidity and sickness absence. On the aggregate level, the individual increases in output due to health improvements lead to increases in total labour productivity (e.g. the output per hour worked, and output per worker).

Elmslie (2012) and Hou et al. (2016) indicated that chronic diseases, especially cardiovascular and respiratory diseases, represent a major fiscal and productivity risk for the economies of developing countries. These diseases have been proven to lower labour productivity, increase health spending, deplete household wealth, and increase income inequities. Besides the reduction in productivity of millions of workers, the rising air pollution causes significant reductions in product quality (Li et al. 2015), and in order to maintain the same level of output, workers usually need to increase working hours (Kjellstrom et al. 2008). OECD (2016) emphasized that the most important feedback paths of air pollution on the economy, in terms of its impact on the GDP, are the reduction in labour productivity and the increases in health expenditures. It is predicted that the global annual market costs of outdoor air pollution will rise from 0.3% in 2015 to 1.0% by 2060.

4 Empirical implementation

In order to empirically examine the relationship between population and the environment and its impact on sustainable development, an econometric model based on the *Recursive Equation System* (RES) is developed. Recursive models are hierarchical as all causal effects are "unidirectional" in nature (Dixon 1999). In these types of models, there is unidirectional dependency among the endogenous variables so the endogenous variables can be determined sequentially (Williams 2015). There must be no feedback from an endogenous variable to one lower in the casual chain (Sobel 1982). This system contains three equations to describe and analyse the complicated relationship between social, environmental, and economic determinants of chances for sustainable development, and to take into consideration the interdependence relations between variables.

4.1 The model

The system consists of an environmental function based on IPAT identity, in addition to health, and labour productivity functions. The model takes the following form:

$$Y_1 = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \varepsilon \tag{1}$$

This equation illustrates the role of population growth as one of the driving forces behind environmental degradation. Air pollution as an example of environmental degradation is determined by the population size (or population growth), along with economic growth, and technology.

$$Y_2 = \beta_0 + \beta_1 Y_1 + \beta_2 x_4 + \beta_3 x_5 + v \tag{2}$$

Equation (2) demonstrates the negative impact of air pollution on the population's health, which is determined by the level of environmental degradation, along with income and education of the population.

$$Y_3 = \delta_0 + \delta_1 Y_2 + \delta_2 x_5 + \delta_3 x_6 + \theta \tag{3}$$

Equation (3) indicates the adverse impact of poor health on labour productivity, which is determined by the health level of the population, technical progress, and the educational level of the population. According to this model, the initial function (Y_1) can be estimated independently, and then the equilibrium value of the second variable (Y_2) is to be determined sequentially, then the equilibrium value of the third variable (Y_3) is consequently determined in accordance with it. *The Ordinary Least Squares* (OLS) method can be used to estimate this model when its assumptions are met. The OLS technique is the most common method for carrying out classical linear regression analysis and estimating econometric models (Poole and O'farrell 1970), because it obtains the best possible results and it can consider complex relationships (Pedace 2013).

With regard to the equations contained in the model, many studies suggest that the explanatory variables are not independent, but that they are related to each other, which indicate the existence of a *Multicollinearity* problem when estimating this model. This problem can be solved by differencing the data instead of using the level data in estimating the model (Sackrin 1962; Baldwin 1966; Heim 2009; Lis 2013), thus the regression equation takes the following form:

$$\Delta Y_t = \beta_1 \Delta x_{1t} + \beta_2 \Delta x_{2t} + u_1 \tag{4}$$

A number of studies illustrated that differencing the data has some advantages, as it eliminates the intercorrelation between the explanatory variables, and reduce serial correlation of residuals (Sackrin 1962; Heim 2009). It should be noted that using this method has a shortcoming, because it leads to loss of the initial observation (Baldwin 1966). *Autocorrelation* is another important problem associated with using a time series data set. It refers to the existence of a correlation between the observed values of the variable over time. The occurrence of this problem means that error terms are not independent over time. To correct for serially correlated disturbances, an adjustment is made for autocorrelation using the *Maximum Likelihood Method*.

The model can be transformed into a stochastic version by taking the logarithm of both sides of the equation, where it becomes additive rather than multiplicative, and adding a residual term. The aim of adding the residual term is to indicate both random measurement errors and the effects of the unobserved variables such as social factors (Cramer 2002). Accordingly, the study suggests using the linear-logarithmic formula[9] of the IPAT model, which assumes that the variables grow at a steady rate, in order to examine the relationship between population growth, economic growth, and technology on one hand, and the emissions of carbon dioxide, as an indicator of environmental degradation, on the other hand.

There is some evidence that the activation of environmental protection laws and legislations plays a significant role in protecting the environment, especially in developing countries (Abdel Razek 2005), this variable has been ignored in all the previous models used in examining the relationship between population growth and the environment. The study suggests adding this factor into the model, which now takes the following form:

$$\ln I = \alpha_0 + \alpha_1(\ln P) + \alpha_2(\ln D) + \alpha_3(\ln T) + \alpha_4 G + \varepsilon \tag{5}$$

Equation (5) indicates that environmental impact in terms of air pollution (*I*) is determined by: population growth (*P*), economic development (*D*), the level of technology (*T*), and the extent of activation of environmental protection laws and legislations (*G*).

$$\ln H = \beta_0 + \beta_1(\ln I) + \beta_2(\ln A) + \beta_3(\ln E) + v \tag{6}$$

Equation (6) illustrates that health level (*H*) is determined by air pollution (*I*), income (*A*), and educational level (*E*).

$$\ln L = \delta_0 + \delta_1(\ln H) + \delta_2(\ln F) + \delta_3(\ln E) + \theta \tag{7}$$

Finally, Eq. (7) illustrates the adverse effect of poor health on labour productivity (*L*) which is determined by health level (*H*), technical progress (*F*), and educational level (*E*).

4.2 The variables

The study used the following variables: total annual emissions of carbon dioxide (*I*), as an indicator of air pollution. CO_2 can be used as a reliable proxy for air quality due to many reasons: It is released from the combustion of fossil fuels, so it represents a good proxy for other air pollutants related to combustion, also CO_2 is a general proxy for indoor pollutants

[9] Using differenced data.

emitted by humans (Benson 2005; European Commission 2010), CO_2 emissions have a high positive correlation with other air pollutants, especially with NO_X and SO_2 (Hoffmann et al. 2005), it is the main contributor to GHGs and it is thought to be responsible for global warming and consequent climate change more than any of the other climate factor drivers (World Bank 2010; Barton 2000; Solomon et al. 2009), CO_2 is considered the most valid proxy for climate change and therefore it has commonly been used across climate literature (Olsen 2007).

Moreover, policies aiming at improving air quality and those aiming at climate change reduction enjoy mutual benefits, as climate change reduction actions can help decrease air pollution and vice versa (European Commission 2010). This variable (*I*) is used as a dependent variable in the first equation, and an explanatory variable in the second equation.

The explanatory variables included in the first equation are as follows: the annual population size (*P*), as an indicator of the pressure caused by the population in increasing carbon dioxide emissions, where it is expected that population growth leads to an increase in carbon dioxide emissions. Despite the important impacts of the demographic factors other than population growth (such as urbanization, migration from rural to urban, and changes in age and gender structures) on the environment and natural resources use, all these factors are strongly linked to the population size and growth rate (Romano 2007; UN 2011). They arise from, and are highly dependent on, the growth rate of the population; thus, it can be said that population growth is the most important demographic factor as most of the other demographic factors tend to associated with it. Accordingly, population growth is used as the main demographic driving force behind the environmental degradation.

The GDP at constant prices (*D*) is used to express economic growth, where it is expected that the growth of real GDP leads to an increase in carbon dioxide emissions. Energy use (*T*), expressed in Kg oil equivalent per $1000 of real GDP, is used as an indicator of the intensity of energy use in economic activities, where the greater the amount energy used to produce a unit of GDP, the lower is the efficiency of energy use and the higher are the carbon dioxide emissions. Finally, a dummy variable (*G*) is used as an indicator of the activation of environmental protection laws and legislations.

The variables included in the second equation are as follows: the annual mortality due to outside air pollution (specifically, annual mortality due to respiratory and cardiovascular diseases). Cardiovascular disease and chronic respiratory conditions are considered to be among the leading causes of disability in developing countries (Pechak and Thompson 2007), where high air pollution levels considered to be its main cause. Cause-specific mortality rates can provide information about the prevalence of a disease, and the morbidity and disability status due to that disease.

These also give information about the most important causes of death, which can be used to design intervention programs addressing these causes (UN 2001b). Accordingly, mortality rate due to cardiovascular and respiratory diseases can be used as a valid indicator for poor health due to air pollution.

This variable (*H*) represents the health impact caused by the increase in carbon dioxide emissions. The explanatory variables of the equation are as follows: the total annual emissions of carbon dioxide (*I*), as an indicator of air pollution, where the increase in carbon dioxide emissions is expected to increase the incidence of respiratory and cardiovascular diseases, or deaths due to these diseases. The second variable is the real GDP per capita (*A*), as an indicator of income, where it is expected that a lower income per capita leads to an increase in the incidence of respiratory and cardiovascular diseases. Finally, the education index (E) is included as an indicator of the educational level, where low levels of education are expected to increase the incidence of respiratory and cardiovascular diseases.

The variables included in the third equation are as follows: the real GDP per hour worked (L) as an indicator of the impact of poor health on labour productivity. Labour productivity is considered to be the key source of economic development, especially in developing countries, where the agricultural sector and other sectors depending on physical power (e.g. building and construction, fishing, and mining) are the main sources of economic growth (Zivin and Neidell 2012). The prevalence of environment-related diseases has adverse impacts on workers in these sectors, manifesting as lower labour productivity due to reductions in physical capacity, especially for low-skilled agricultural and factory workers (Kjellstrom et al. 2009; Lichter et al. 2015), and lower employment chances for less healthy workers (Dillon et al. 2014). It has been reported that the major impacts on labour productivity caused by climate change[10] and air pollution occur in regions with relatively large populations of outdoor workers and warm climate (OECD 2015). Accordingly, labour productivity can be used as a reliable indicator of the economic performance.

The explanatory variables of the equation are as follows: the poor health (H), as defined above, where the poor health is expected to decrease the labour productivity. The second variable is the total factor productivity (F), as an indicator of technical progress, where it is expected that a higher total factor productivity leads to an increase in the labour productivity. Finally, the education index (E) is included as an indicator of the educational level, where low levels of education are expected to decrease labour productivity. Table 1 gives the definitions of all variables included in these three equations.

4.3 Data

The data used in this study are a time series data set for the Egyptian economy during the 1960–2010 period, this set includes ten variables. Emissions of carbon dioxide, Kg oil equivalent per $1000 of real GDP, population (size and growth rate), GDP at constant prices (absolute value and growth rate), and GDP per capita are from the World Development Indicator (WDI), World Bank database.

Health data are represented by mortality due to outside air pollution, particularly annual deaths due to respiratory and cardiovascular diseases, based on a range of primary sources. Data for the period of 1962–1969 are acquired from a comparative study of death and its causes and expectations in Egypt, published in 1975 by the Department of Biostatistics and Demography, Cairo University. For the years from 1976 to 1988, data were collected from a Doctoral Thesis about analysing recent mortality data in Egypt with concentration on death causes, published in 1990 by the Faculty of Medicine, Cairo University. Data for the years (1998, 1999, and 2000) were acquired from a Doctoral Thesis published in 2002 by the Faculty of Medicine, Ain Shams University, focused on the assessment of death causes in different regions of Egypt. The rest of data were collected from the Egyptian National Information Center for Health and Population (NICHP).

The sources of the education data represented in Education Index are the annual reports of human development and the annual development reports issued by the United Nations Development Program (UNDP). There was a lack of published data for the Education

[10] Losses projections for the most vulnerable countries are estimated to be more than 2% of the total working time, and about 20% output reductions in the affected sectors, amounting to a global economic loss by more than 2 trillion USD by 2030.

Table 1 Definition and measurement of variables used in the study: 1960–2010

Variable	Definition	Measurement
Emissions of carbon dioxide	Total annual emissions from all sources	Kilotons
Population size	Total population	Number
GDP at constant prices	Constant at 2000 $US	US Dollar
Kg oil equivalent per $1000 of real GDP	Constant at 2000 $US	Kilotons
Activation of environmental laws and legislations	Dummy variable	Number (0, 1)
Mortality due to outside air pollution	Annual deaths due to respiratory and cardiovascular diseases	Number
GDP per capita	Constant at 2000 $US	US Dollar
Education index	Mean years of schooling and expected years of schooling	Number
GDP per hour worked	Constant at 2000 $US	Number
Total factor productivity	Residual of (Cobb–Douglas) production function estimation	Number

Index for some years especially during the 60's period. Accordingly, the Education Index has been calculated for the missing years; fortunately, the primary data needed for the calculation are available. Education Index is obtained out of two sub-indices, the adult literacy rate and gross enrolment rate, with relative weights of 2/3 and 1/3, respectively.

The data of total hours worked were collected from two main sources. Data for the period of 1960–1999 are drawn from five unpublished labour force surveys made by the Arab Labour organization (ALO), League of Arab States.[11] For the period of 2000–2010, the data were obtained from the Egyptian Central Agency for Public Mobilization and Statistics (CAPMS) database. The data of the real GDP per hour worked for the period of 1960–2010 are calculated by dividing the annual GDP (constant at $2000) by the annual hours worked.

Total factor productivity (TFP) is used in this study as a measure of the Egyptian economy's long-term technological change. Data for the period of 1990–2010 come from The Conference Board (TCB) Total Economy database. The TFP data for the period of 1960–1989 have been calculated. It should be noted that TFP cannot be measured directly. Instead, it is a residual, which indicates changes in total output not caused by inputs. TFP has been calculated using a simple *Cobb–Douglas* production function. The data set used is from the World Development Indicator (WDI), World Bank database. Thus, the TFP has been measured using the following formula:

$$\text{TFP}_t = O_t / M_t^{\alpha} K_t^{(1-\alpha)}$$

where (O) is the economic output represented by the GDP at constant prices, (M) is the total number of permanent employees, (K) is the capital formulation, the relative contribution of the labour force expressed by (α) and ($1 - \alpha$) indicates the capital share.

[11] According to the ALO, hours worked represent regular hours worked by full-time and part-time workers, paid and unpaid overtime, hours worked in additional jobs, and time not worked because of public holidays, annual paid leaves, strikes and labour disputes, bad weather, economic conditions, and other reasons.

5 Results

In this section, the results of both descriptive and regression analysis will be introduced.

5.1 Descriptive statistics

Figure 3 shows the Egyptian annual statistics on carbon dioxide emissions for the period of 1960–2010. There is an overall upward trend in emissions during the study period with a sharp acceleration since 1995. The little dip in the beginning of the 2000's may have occurred as a consequence of the economic recession caused by the energy crisis and its negative impact on the Egyptian economy.

Figure 4 shows the energy intensity[12] of the economy represented in kilotons of oil equivalent per 1000$ of real GDP. Energy intensity is a measure of the energy efficiency of the economy, the higher the energy intensity, the higher is the cost of converting energy into GDP. It is noticeable that the intensity of energy use had a steady growth rate over the study period, with acceleration during the period of 2000–2010.

Figure 5 illustrates that population size has doubled during the study period. However, the growth rate has fluctuated. Figures 6 and 7 present the changes in GDP and its annual growth rate during the period of 1960–2010. Although there is an upward trend in the Egyptian GDP in absolute value, the growth rate has fluctuated to a great extent. It increased to reach 14.63% in 1976 and decreased to be 5.15% in 2010. The high growth rate in 1976 has been a consequence of the Openness Policy applied during the period 1974–1982, which aimed at attracting foreign investment through a series of incentives. Although the economy initially expanded due to that policy, this has proven to be unsustainable and the growth rate has consequently decreased.

Figure 8 shows a substantial growth in GDP per capita during the period of 1960–2010, with an average annual increase of 7% during that period. Figure 9 presents the annual mortality due to outside air pollution, specifically respiratory and cardiovascular diseases during the period of 1960–2010. There is a sharp acceleration in the number of deaths due to these diseases after the period of 1960–1970. The estimated average for annual growth of the number of deaths due to respiratory and cardiovascular diseases was about 3.3% during the period of 1960–2010.

Finally, Fig. 10 presents the GDP per hour worked (constant at $2000) as a measure of labour productivity for the 1960–2010 period. Clearly, there was an upward trend in the GDP per hour worked during the period of 1977–1992, where it reaches its maximum value, which reflects an increasing labour productivity during that period. It can be concluded that growth in income over the same period was driven by that growth in labour productivity. After 1992, there was a downward trend in GDP per hour worked, and correspondingly, the labour productivity. Low labour productivity and declining growth rate can reflect less utilization of capital, rising employment of low-productivity workers, an increase in the number of working hours without a corresponding increase in production, or general failure in labour utilization.

These descriptive analyses tend to suggest that for the first equation, the substantial increase in CO_2 emissions could correlate during the study period with population growth as well as with economic growth. The zero-order correlation of variables in Table 2

[12] Increasing energy intensity refers to energy use inefficiency, increase energy efficiency leads to reductions in carbon dioxide emissions.

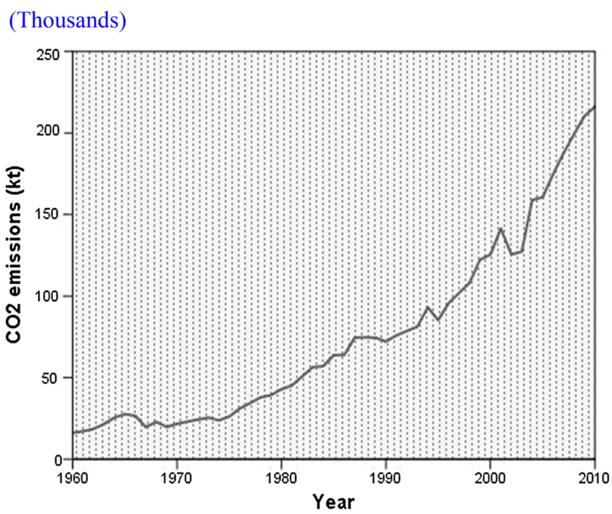


Fig. 3 Egyptian annual carbon dioxide emissions: 1960–2010. *Source*: WDI database

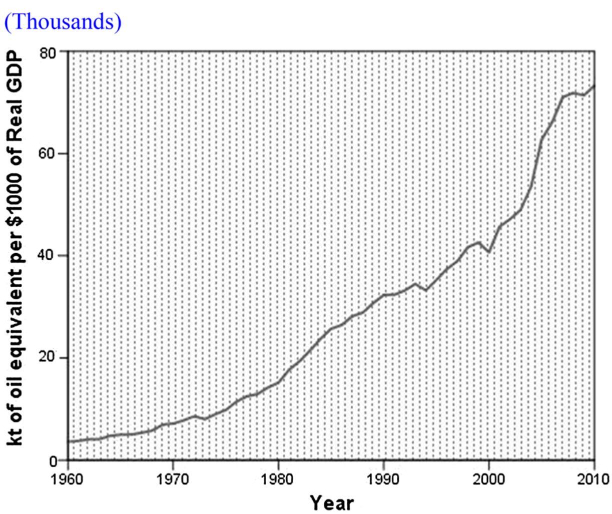


Fig. 4 Kg oil equivalent per $1000 of GDP (constant 2000 US$): 1960–2010. *Source*: WDI database

tentatively supports this assertion: Population ($r = 0.465$), GDP ($r = 0.419$) and energy intensity ($r = 0.126$) are positively correlated with carbon dioxide emissions.

For the second equation, the descriptive analysis as shown in Table 3 suggests that mortality due to outside air pollution is positively correlated with CO_2 emissions ($r = 0.414$) and negatively correlated with educational level ($r = -0.389$). Finally, the analysis of the third equation as shown in Table 4 suggests that labour productivity is negatively correlated with poor health ($r = -0.605$) and positively correlated with TFP ($r = 0.485$) and educational level ($r = 0.392$). The correlation coefficients of the

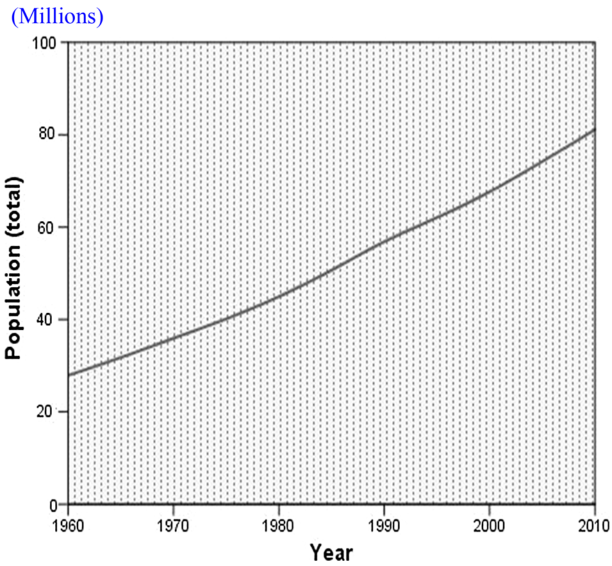


Fig. 5 Egyptian population: 1960–2010. *Source*: WDI database

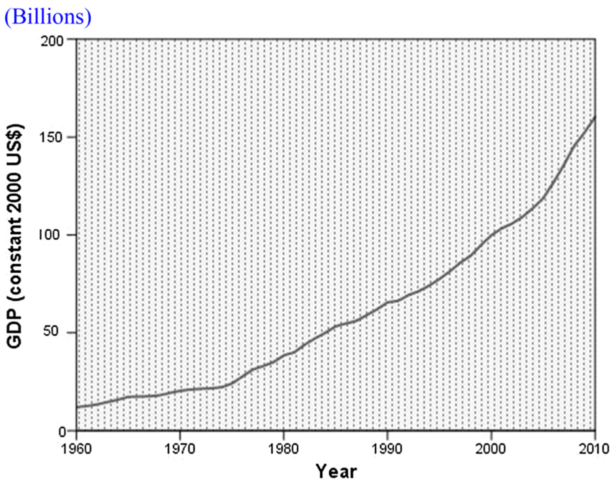


Fig. 6 Egyptian GDP (constant 2000 US$): 1960–2010. *Source*: WDI database

independent variables used in the three equations indicate the absence of a multicollinearity problem. In the next section, further examination of these complex relationships in the regression model will be presented.

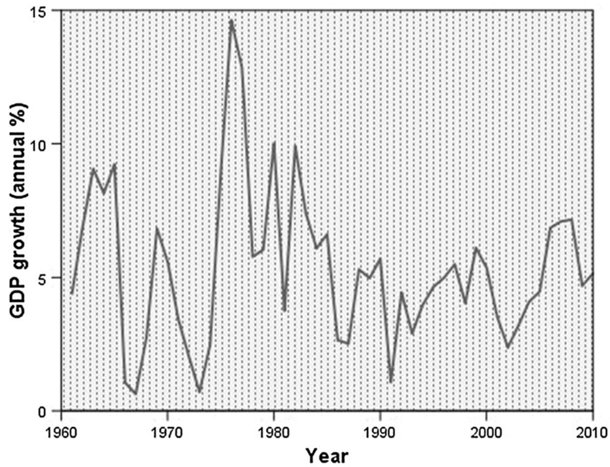


Fig. 7 Egyptian annual GDP growth rate: 1960–2010. *Source*: WDI database

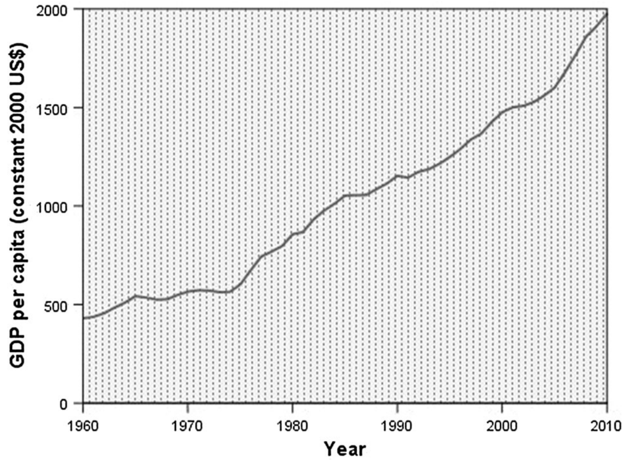


Fig. 8 Egyptian GDP per capita (constant 2000 US$): 1960–2010. *Source*: WDI database

5.2 Regression results

The next section provides estimation results of the *Recursive Equation System*, which contains the environmental, health, and labour productivity functions. Assuming that the three functions are embedded in a recursive system, then the total effect of various exogenous variables as measured by a system of equations could be quite different from the direct effect alone estimated by the previous studies. Although this system of equations might seem simultaneous, it is actually recursive, where the endogenous variable (I) in the first equation is an exogenous variable in the second equation. And the endogenous variable (H) in the second equation is an exogenous variable in the third equation. The

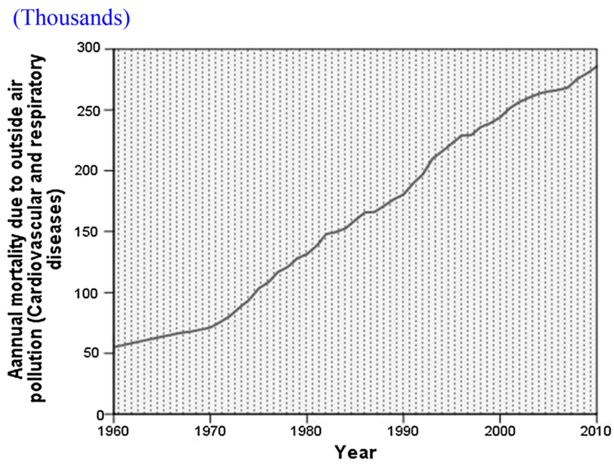


Fig. 9 Annual mortality due to outside air pollution (respiratory and cardiovascular diseases): 1960–2010. *Note* health data collected from various sources. Data for the 1962–1969 period acquired from a comparative study of death and its causes and expectations in Egypt, published in 1975 by the Department of Biostatistics and Demography, Cairo University. For the years from 1976 to 1988, data were collected from a Doctoral Thesis about analysing recent mortality data in Egypt with concentration on death causes, published in 1990 by the Faculty of Medicine, Cairo University. Data for the years (1998, 1999, and 2000) were acquired from Doctoral Thesis published in 2002 by the Faculty of Medicine, Ain Shams University, focused on the assessment of death causes in different regions of Egypt. The rest of the data were collected from the Egyptian National Information Center for Health and Population (NICHP). *Source*: Ahmed (1990), Najem (1975), NICHP (1989), Saied (2002) and NICHP database

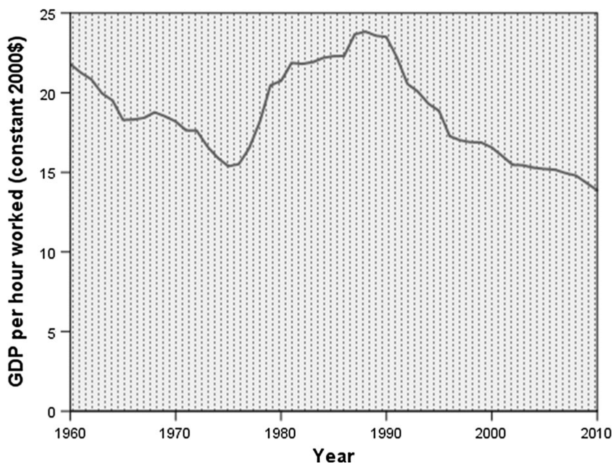


Fig. 10 GDP per hour worked (constant 2000 US$): 1960–2010. *Note* Total hours worked data for the period 1960–1999 are drawn from five unpublished labour force surveys made by Arab Labour organization (ALO), League of Arab States. For the period of 2000–2010, the data were obtained from the Central Agency for Public Mobilization and Statistics (CAPMS) database. *Source*: ALO; CAPMS database

Table 2 Correlations of variables used in Eq. 5: 1960–2010

Variable	(1)	(2)	(3)	Mean	SD	Min	Max
(1)				75.46	56.87	16	216
(2)	0.465 (0.013)			51.9	15.9	27.9	81.12
(3)	0.419 (0.001)	0.136 (0.044)		27.47	21	3.6	73.3
(4)	0.126 (0.001)	0.026 (0.429)	0.320 (0.012)	60.14	41.84	12	160.26

All variables are in logarithmic form

P values are in the parentheses

(1) CO_2 emissions in thousands

(2) Population in millions

(3) GDP (constant at $2000) in billions

(4) Kg oil equivalent per $1000 of real GDP in thousands

Table 3 Correlations of variables used in Eq. 6: 1960–2010

Variable	(1)	(2)	(3)	Mean	SD	Min	Max
(1)				161.9	64.46	55	222.5
(2)	0.414 (0.031)			75.46	56.87	16	216
(3)	0.433 (0.324)	0.424 (0.001)		1026	445	430.36	19,755.55
(4)	−0.389 (0.003)	0.084 (0.280)	0.332 (0.009)	5.1	1.6	2.3	7.3

All variables are in logarithmic form

P values are in the parentheses

(1) Mortality due to outside air pollution in thousands

(2) CO_2 emissions in thousands

(3) GDP per capita (constant at $2000)

(4) Education Index

Table 4 Correlations of variables used in Eq. 7: 1960–2010

Variable	(1)	(2)	(3)	Mean	SD	Min	Max
(1)				1893.7	558.6	1005	2503.5
(2)	−0.605 (0.000)			161.9	64.46	55	222.5
(3)	0.485 (0.005)	−0.29 (0.008)		1.48	1.46	−0.90	4.25
(4)	0.392 (0.002)	−0.240 (0.022)	0.377 (0.046)	5.1	1.6	2.3	7.3

All variables are in logarithmic form

P values are in the parentheses

(1) GDP per hour worked (constant at $2000)

(2) Mortality due to outside air pollution in thousands

(3) Total factor productivity

(4) Education Index

Table 5 Unstandardized coefficients from the regressions of the recursive system of equations: 1960–2010

Explanatory variables	Dependent variables		
	Emissions of carbon dioxide	Mortality due to outside air pollution	Labour productivity
Intercept	−1.99	1.08*	3.60
Population	2.401***	–	–
Economic growth	2.416***	–	–
Energy use	0.392**	–	–
Activation of environmental laws	−0.422***	–	–
Emissions of carbon dioxide	–	2.487***	–
Affluence	–	1.716	–
Educational level	–	−0.355**	–
Mortality due to outside air pollution	–	–	−1.584**
Total factor productivity	–	–	0.781***
Educational level	–	–	0.619*
Fitness statistics			
R-squared	0.773	0.786	0.631
Adjusted *R*-squared	0.753	0.773	0.608
Durbin–Watson stat	2.144	2.252	2.201
Sample: 1960–2010			
Included observations: 51			
Total system (balanced) observations 153			

All variables are in logarithmic forms except both the activation of environmental laws (dummy variable) and TFP series (has negative numbers)

The error terms are adjusted using maximum likelihood methods

* $P < 0.10$; ** $P < 0.05$; *** $P < 0.01$

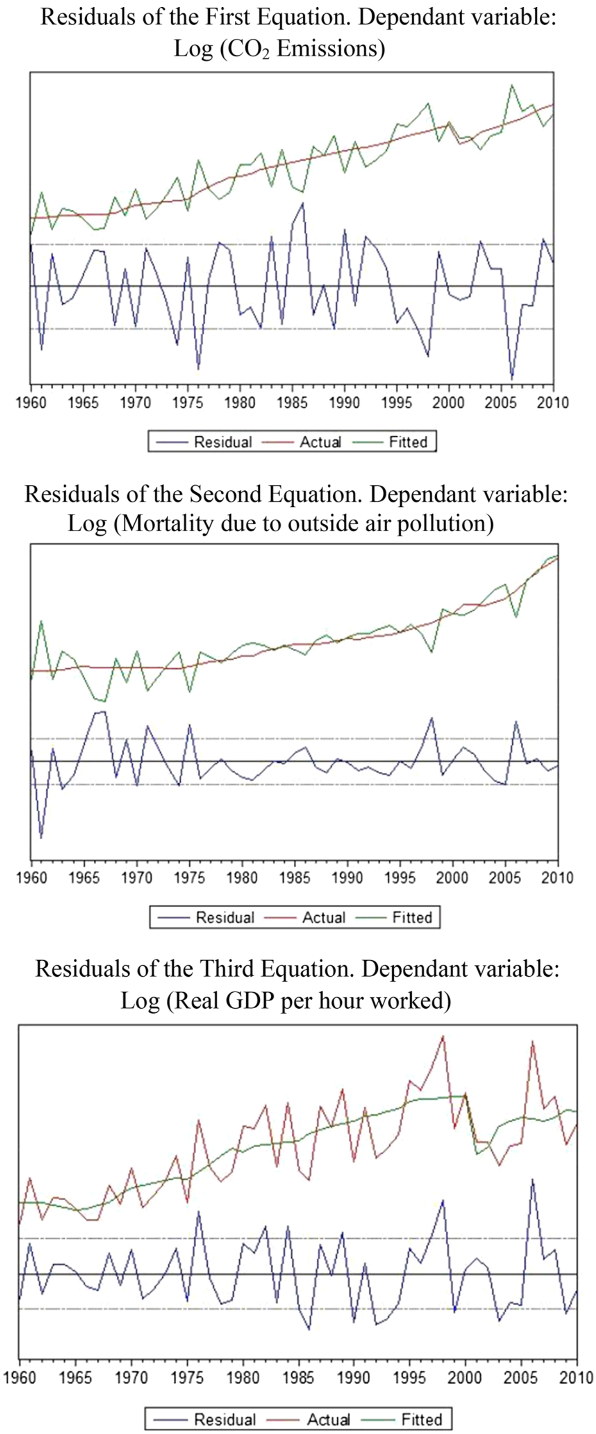
analysis is done using the OLS technique, which is the appropriate estimation procedure of a recursive model of this sort.

5.2.1 The role of population on emissions

The assessment of the population pressures on carbon dioxide emissions is illustrated in column 2 of Table 5 which shows the first equation estimation, with real GDP, population, energy use intensity, and a dummy variable used to indicate the activation of the environmental protection laws and legislations as the explanatory variables, and total CO_2 emissions as the dependent variable. Both the dependent and explanatory variables are all in natural logarithm form except for the dummy variable. The model provides a good fit, with an adjusted *R*-squared statistic equal to 0.75. The Durbin–Watson (DW) statistic is in the neighbourhood of 2 (specifically 2.14), suggesting an absence of serial correlation of error terms. See system residuals estimation in Fig. 11.

A positive association between population growth and emissions is confirmed. A 1% increase in population raised the CO_2 emissions by 2.4%. In addition, a positive

Fig. 11 System residuals estimation



relationship between economic growth and emissions is also confirmed. A 1% increase in real GDP raised the CO_2 emissions by nearly 2.48%. The results also indicate a positive association between the increase in intensity of energy use or the energy inefficiency and the CO_2 emissions. An increase in energy use intensity by a 1% could lead to an increase in emissions by less than half a percentage point (0.40%). Finally, the results show a slight role of deactivation of environmental protection laws and legislations in increasing CO_2 emissions.

5.2.2 The impact of emissions on health

To test the hypothesis that air pollution has an adverse impact on health status, the second equation has been utilized, with total CO_2 emissions, GDP per capita, and educational level as the explanatory variables and mortality due to outside air pollution, specifically respiratory and cardiovascular diseases, as the dependent variable. The dependent and explanatory variables are all in natural logarithm form. The estimation result is shown in column 3 of Table 5. This model fits the data well, with an adjusted *R*-squared statistic equal to 0.77 and the DW statistic is in the neighbourhood of 2 (specifically 2.25). See system residuals estimation in Fig. 11.

The results emphasize a positive association between mortality due to outside air pollution and carbon dioxide emissions. An increase in CO_2 emissions by 1% is associated with an increase in deaths due to respiratory and cardiovascular diseases by 2.5% approximately. In contrast, the results show that there is a negative association between education and health. An increase in the educational level leads to a slight reduction in the incidence of respiratory and cardiovascular diseases. According to the results, the affluence has no significant effect on reducing morbidity and mortality due to outdoor pollution.

5.2.3 The impact of health on productivity

The estimation of the third equation is illustrated in column 3 of Table 5, and this equation tests the hypothesis that poor health has adverse impact on labour productivity. The variables included in this equation are as follows: poor health, total factor productivity, and educational level as explanatory variables, and labour productivity as the dependent variable. The dependent and explanatory variables are all in natural logarithm form. The model provides a good fit, with an adjusted *R*-squared statistic equal to 0.60. The DW statistic is in the neighbourhood of 2 (specifically 2.2). See system residuals estimation in Fig. 11. Results show a negative association between poor health and labour productivity. Poor health leads to a decrease in labour productivity by more than one and half percentage point (−1.58%). In contrast, there is a positive association between both the technology improvements and educational level on one side and labour productivity on the other side.

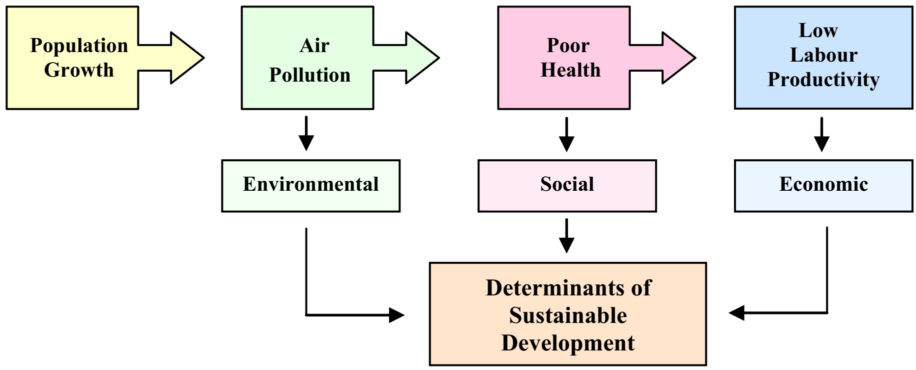
6 Discussion and conclusions

Understanding sustainable development linkages and the techniques for achieving it requires novel methodologies based on comprehensive analytical methods in order to analyse the economic, social, and environmental status, along with the interactions between them. Information regarding cause–effect relationships between all the three dimensions is still lacking, as the interrelationships between them have not been entirely explored and understood.

Yet, the vast majority of studies which dealt with the determinants of sustainable development through analysing the relationship between population and the environment have concentrated on the impact of population growth on the environment, especially air pollution, by adopting *Single-Equation Models* (SEM), and ignored that environmental deterioration in turn has adverse impacts on population in terms of health level and labour productivity.

To capture both the direct and indirect effect of population growth on chances for sustainable development, SEM may not be appropriate. For example, the observed impact of air pollution on health in SEM cannot be fully attributed to air pollution alone, but also to change in the rate of population growth as well. Also, some of the variations in the labour productivity, which ought to be attributed to poor health, could be attributed to population growth via the negative effect of pollution on health.

In this study, an attempt is made to remedy this deficiency by introducing a causal pathway framework through developing a more comprehensive model containing potential explanatory variables, which could determine chances for sustainable development. Particularly, trying to understand the way population growth hinders sustainable development, reasoning that population growth can influence the determinants of sustainable development via its negative impact on the environment, which in turns has adverse effects on health, consequently lowering labour productivity.



This argument was followed in developing a *Multi-Equation Model* (MEM) based on a *Recursive System of Equations*. This model is an attempt to shift the assessment of the relationship between population and the environment in the direction of causal analysis, that is, trying to perceive the sources or roots of some environmental, social, and economic problems in order to understand their correlations, which could be useful in assisting policymakers in developing appropriate solutions or ways to fix them.

The major findings of the current study support the claim that population growth is one of the major driving forces of environmental degradation, represented by the increase in carbon dioxide emissions in Egypt. It is found that a 1% increase in population is associated with a 2.4% increase in carbon dioxide emissions.[13] Therefore, policymakers should

[13] This magnitude is larger than the one estimated by some other studies that used panel and cross-sectional data analysis, which suggested that a 1% increase in population raises emissions by 1–1.67%.

seek a change in the current population growth path into a more desirable one. This change should include adaptation of population policies and strategies aiming to enhance voluntary family planning programs, reduce desired family size, and encourage delays in childbearing.

In fact, since 1960s, Egypt has implemented a number of population policies and a family planning program aiming at reducing the total fertility rate (TFR). Egypt's family planning program has achieved considerable progress during the period 1980 through 2005, but this program was subject to many obstacles caused by a decline in international grants funding it (CEFRS 2015). Currently, Egypt should search for alternative sources to fund the family planning program and other population policies, which is a great challenge, especially in the light of the current economic crises in Egypt.

As illustrated in this study, economic growth[14] and energy use are associated with a monotonically upward trend in emissions. Thus, another potential policy intervention for reducing carbon emissions could also be in the area of raising energy efficiency, in other words, decreasing the intensity of energy use for economic production. The results also emphasized that the absence of activation of environmental protection laws and legislation in Egypt during the study period has played a significant role in increasing carbon dioxide emissions, thus air pollution and environmental degradation in general.

Although Egypt was one of the first Arab countries to join the global efforts facing climate change since the Earth Summit in 1992, and to approve the United Nations Framework Convention on Climate Change (UNFCCC) in 1994, in addition to signing the Kyoto Protocol in 1999 (Agrawala et al. 2004), environmental protection in Egypt is troubled by the ineffectiveness of environmental policies and deficiencies in their implementation (UN 2015), in addition to institutional weaknesses represented by the existence of many ministries and governmental agencies that are responsible for developing environmental legislation, and the limited powers for decision-making in local administrations (Egypt's Country Strategy: 2007–2013). In this regard, Egypt is in a deep need to improve the environmental legislation to overcome the weakness in the environment sector.

There has been an increasing concern over the possible impact of air pollution and climate change on population health level, but empirical work on the issue is still at an early stage. The findings of this paper provide new evidence that air pollution has been one of the major causes of increasing morbidity and mortality, especially due to cardiovascular and respiratory diseases, over the last few decades in Egypt. My findings illustrate that an increase by 1% in carbon dioxide emissions is associated with nearly 2.5% of mortality due to outside air pollution in terms of respiratory and cardiovascular diseases. Part of this increase in mortality caused by outside air pollution and incidence of environment-related diseases can be attributed to the population pressure which raises CO_2 emissions.

The way to handle the health problems caused by environmental degradation especially climate change and air pollution is one of the most important obstacles facing Egypt in its sustainable development endeavour. The ability of the Egyptian health sector to deal effectively with various direct and indirect health impacts of air pollution and climate change is limited by the inefficiency and disorganization of the health system, and resources scarcity in the health sector. Currently, there are no efforts or adaptation strategy for Egypt to respond to the impacts of climate change and air pollution on health. To improve the Egyptian health sector's response to air pollution threats, planning should be

[14] Recent studies used panel data analysis have suggested an inverted U-shaped relationship between economic growth in terms of GDP per capita and emissions, which is known as the *Environmental Kuznets Curve (EKC)* where the emissions initially get worse but lately improve with income.

on population-based, in addition to allocating more investments and resources in this sector, and managing the limited resources efficiently and effectively.

Evidence from various studies emphasized that income is a significant determinant of population health level. My findings indicate that affluence, or the increase in GDP per capita did not play a significant role in reducing the incidence of environment-related diseases in Egypt during the study period. This result can be attributed to many reasons, such as the increasing intensity of energy use in production, the dependence of the industrial sector on fossil fuels, and the deactivation of environmental protection laws. Educational level in Egypt, as the findings show, has a slight negative association with health. Although education largely determines an individual's residence, and his ability to control the quality of the environment in which he lives, diseases related to outside air pollution cannot be avoided easily.

As Egypt has a limited natural resources base, it should rely on human resources as the main factor to achieve sustainable economic development and improve the population living standards in the global marketplace, in other words, Egypt competitiveness depending on the quality of its human capital in terms of skills, education, and health. Although the impact of population health on labour productivity has become a significant policy concern, the empirical work on the causes of low labour productivity has given little attention to the role of health status as an explanatory variable.

According to the ILO, the proportion of Egyptian workers in the agriculture sector represented about 29.2% of total labour force in 2011, while the workers in production and construction sectors are estimated to be nearly 23.5%, meaning that close to 50% of the Egyptian labour force are outdoors workers and therefore more vulnerable to the adverse effects of air pollution and climate change. Findings of this study indicate that a significant part of the low productivity of the Egyptian labour force can be explained by poor health of the population. A portion of this negative impact of poor health on labour productivity can be attributed to the negative impact of air pollution and climate change on health, which is driven among other factors by population growth.

It should be noticed that the problem of low labour productivity in Egypt could probably be associated with social factors, for example an increasing dependence on unskilled workers, and mismatches between the educational system outcomes and labour market needs. Labour market policies in Egypt during the past few decades have proven to be ineffective in solving labour market problems and creating enough productive jobs for all job seekers (Amin 2014). So, it is very important for Egypt, which has a very low level of labour productivity, to have a better understanding of all the factors that determine its labour productivity level, and pay more attention to the health impact on labour market outcome.

In accordance with the evidence of the causality links between air pollution and poor health outcomes, and between poor health and labour productivity, it can be said that policies and procedures to reduce air pollution can be also be considered as an investment in human capital, and therefore a tool for enhancing economic growth. So, programs aiming at protecting the environment should be closely related to those aiming at protecting human health.

Generally, the empirical findings obtained from the recursive equations model provide some evidence that the relationship between population and the environment follows a complex process. However, it was established that population growth plays a significant role in increasing CO_2 emissions and that air pollution in turn raises health risks significantly, and this increase in the level of morbidity and mortality due to air pollution finally negatively affects labour productivity. From this paper's findings, it can be concluded that variables which determine the environmental, social, and economic status can also determine the chances for sustainable development of the economy. Failure to recognize the behavioural effects among the variables could be a probable reason for the difficulty facing the interpretation of the traditional results properly.

From the evidence available, it can be argued that without adequate theorizing, it could not have been argued that the high growth in population was one of the main hindrances to sustainable development in Egypt. It can also be concluded that the impact of population growth on sustainable development chances will depend on how much the rise in air pollution decreases labour productivity through raising the rate of morbidity and mortality. Finally, it can be said that even when rapid population growth rate plays a minor role in creating a specific problem, such as its indirect negative impact on labour productivity and thus economic growth, population management policies may still constitute a viable measure for dealing with that problem, especially with respect to policy intervention cost.

6.1 Chances for sustainable development in Egypt

As the preceding discussion clarified, Egypt is in a deep need to spend more efforts to support the transition beyond economic development and to achieve sustainable development. This transition depends on turning away from the current fixed planning orientation to a more flexible system relaying on a broader vision for the national sustainable development strategy. In general, there are some key principles or common desirable features in any sustainable development strategy. Such strategy should be based on a solid analytical base and reliable information about the current interrelationships between economic, social, and environmental aspects, and their implications for strategy objectives. A strategy should also contain an inclusive review of the present situation and forecasts for trends and risks. Finally, a strategy should ensure that the beneficial effects on disadvantaged groups among the population are sustainable. In other words, the strategy for sustainable development should be a tool and an instrument to achieve the maximum utilization of the human, financial, and natural resources.

Thus, in order to achieve its goal of sustaining the development, Egypt should adapt a national strategy which has three dimensions: economic, social, and environmental. The main purpose of that strategy should be realizing the maximum integration between economic, social and environmental policies and plans, through clearly identifying alternatives, objectives, and targets for development, working on building capacities in various fields, enhancing coordination between the various society sectors, setting a legislative framework sufficient to protect natural resources, facilitating efficient allocation of the limited resources, and improving the sharing of development benefits in a socially just way.

6.2 Recommendations for further research

The findings in this study are subject to some limitations. The most important is that the data included in the model apply only to Egypt. So, considerably more work needs to be done in order to test the validity of the suggested model through application in a number of countries. This is could be done through using a panel data analysis applied to countries in different income groups, or through bilateral comparisons between select countries according to two different approaches. The first approach is to compare the results of the model for two countries similar in the dependent variable. Accordingly, the criterion would be to select pairs of countries with minimal differences in the dependent variable, accompanied by significant differences the explanatory variables included in the model.

The second approach is to compare the results of testing the model for two countries which are similar in the explanatory variables. Accordingly, the criterion is to select pairs of countries with minimal differences in the explanatory variables, accompanied by significant differences in the dependent variable. Also, more work could be done in the area of global CO_2 emissions projections in the future under a number of population growth scenarios. The current model could also be applied to other kinds of environmental degradation such as water pollution. Thus, further research could be undertaken in the following areas: the driving forces of water pollution, the impact of water pollution on increasing water-related diseases, and the negative effect of water-related diseases on labour productivity.

In a wider view, the development and validation of this model should help in achieving a clearer understanding, along with answering many crucial questions concerning the relationship between population and the environment, and its impact on sustainable development. For example, questions about the nature of environmental problems associated with the demographic factors in developing countries compared to developed ones, and whether these factors affect the environment the same way in all countries. Also, the way environmental degradation threatens the public health in some countries compared to others and the extent that poor public health impacts labour productivity. Finally, whether low labour productivity is a hindrance to achieving sustainable development, and what are the methods and policies which must be followed in order to sustain development and how to overcome the contradictions between policies' priorities in developing the environmental, the social and the economic aspects of the society.

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